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Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

9 OCT 89 14. 07

-R.L. GARWIN-

October 5, 1989

Subject: Chairman's July 20 Request for Summaries of Past and Present Cold Fusion Research and August 9 Request for Tritium Production Results

The following have been received to date from the following individuals in response to the above requests:

N. R. Fleming, U. Michigan (response to August 9 request)

O. G. COllins, Washington State U. (response to August 9 request)

P. N. Samios, BNL (supplementary information)

Q. G. Miley, U. Illinois at Urbana (response to July 20 and August 9 request)

Immediately behind this memorandum is a cumulative index.

Bill
William L. Woodard
Panel Secretary

Enclosures

INDEX

A. Bo U.R. Sundqvist, Uppsala University (response to both requests)

B. W. Scheid, Giessen University (responses to both requests)

C. M.M. Broer, AT&T Bell Laboratories (response to August 9 request)

D. J. Eridon, Naval Research Laboratory (response to August 9 request)

E. Y.E. Kim, Purdue University (response to July 20 request)

F. A Schriesheim, Argonne National Laboratory (response to July 20 request)

G. M.A. Prelas, University of Missouri, Columbia

H. L.R. Greenwood, ANL (response to August 9 request)

I. F. Besenbacher, University of Aarbus (response to July 20 request)

J. N.J.C. Packham (for Bockris), Texas A&M (response to August 9 request)

K. J. Paquette, Atomic Energy of Canada, Ltd.

L. N. Lewis, California Institute of Technology (response to August 9 request)

M. J. Rafelski, University of Arizona (response to August 9 request)

N. P.D. Bond, Brookhaven National Laboratory (response to August 9 request)

O. J.L. Straalsund, Battelle (response to August 9 request)

P. A. Narath, Sandia National Laboratories (response to August 9 request)

Q. W. Appleton, Oak Ridge National Laboratory (response to August 9 request)

R. Texas A&M University (response to August 9 request)

S. T.F. Droege (response to July 20 request)

T. S. Lien, Idaho Operations Office (response to August 9 request)

U. M. Wadsworth, U. Utah (response to August 9 request)

V. J. Farny, Institute of Plasma Physics, Warszaw (response to July 20 request)

W. S. Jones, et.al, Brigham Young University (response to August 9 request)

XYZ. D.R. McCracken, AECL (response to August 9 request)

* * * * * *

BEGIN RED SERIES

A. J.F. Holzrichter, LLNL (response to August 9 request)

B. W. Appleton, ORNL (response to July 20 request)

C. D. Manos, PPPL (response to August 9 request)

D. K.I. Thomassen, LLNL (response to July 20 request)

E. M. Danos, NIST (response to July 20 request)

F. R. Jensen, LANL (response to July 20 request)

G. J. Harb & W. Pitt, Brigham Young U. (response to August 9 request)

H. A. Narath, Sandia National Laboratories (response to August 9 request)

I. S. Pons, U. Utah (response to August 9 request)

J. H. Randolph, Westinghouse Savannah River Co. (responses to July 20 and August 9 request

K. N. Samios, Brookhaven National Laboratory (response to July 20 request)

L. C. White, Naval Research Laboratory (response to July 20 request)

M. H. Law, AT&T Bell Laboratories (response to August 9 request)

N. R. Fleming, U. Michigan (response to August 9 request)

O. G. COllins, Washington State U. (response to August 9 request)

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Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

August 9, 1989

Dr. R. Fleming
University of Michigan
3034 Phoeniz Memorial Laboratory
Bonisteel Boulevard
Ann Arbor, MI 48109

Dear Dr. Fleming:

It is important that the Panel on Cold Fusion of ERAB gathers all possible information on the positive and negative claims of tritium production in electrolytic cells in which solutions of LiOD in D_2O are electrolyzed with Pd(Ti) electrodes. Whatever information you can supply will be greatly appreciated. In particular, please address the following points, inter alia:

1. Source and specific activity of D_2O used in the electrolytic cells.

2. Description of the electrolytic cell, including volume of D_2O.

3. Cell operating conditions.

4. Schedule of additions of D_2O during operation of the cell.

5. Tritium analyses:
   a. Method of purification of samples for analysis
   b. Analytical method
   c. Schedule of cells examined for possible tritium production
   d. Specific activity of D_2O,$D_2(g)$ and PhD_n as a function of time for each cell.

6. Neutron production rate in each cell or in comparable cells.

7. Heat balance measurements in each cell in which tritium is found or in comparable cells.

8. What tritium sources are located in the buildings where the electrolytic cells are operated and/or in the analysis stages.

Any additional pertinent information relative to possible tritium production will be appreciated.

(OVER)

Please send this information to William Woodard (return envelope enclosed) with a copy to Professor Jacob Bigeleisen, Department of Chemistry, State University of New York at Stony Brook, Stony Brook, New York 11794-3400. If possible, please send the material on tritium by September 1, 1989. Recall that we requested a summary of past and present research on cold fusion to be due at DOE by September 15. For reasons of scheduling we wish the tritium data two weeks prior to your summary.

My colleagues and I on the Cold Fusion Panel realize that this is an imposition on your time. However, in order to prepare our final report to the DOE, it is essential that we gather all available information.

Sincerely,

John Huizenga

John R. Huizenga
Co-Chairman, ERAB
Panel on Cold Fusion

Enclosure

21 Sept 89

To: ERAB
From: Ron Fleming

In the "cold fusion" cell reported at Sante Fe by me (Knoll, Donahue, Heuser, Mancini & Fleming), we only looked for Pd-Kxrays. We did not make any attempt to measure ^3H; we did not see any. We also did not attempt to detect neutrons.

I am sorry about the late return. I was away until Sept 6th, and I just uncovered your letter. Good luck!

Washington
State University

Department of Physics, Pullman, Washington 99164-2814 / 509-335-9531

September 20, 1989

John R. Huizenga
Co-Chairman, Cold Fusion Panel
Energy Research Advisory Board
Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Huizenga:

Enclosed please find a summary of my past and present research on cold fusion. My report is a little past your deadline, but I hope it will still be useful to the ERAB.

There are three copies of the summary, and attached one copy each of two manuscripts describing novel theories of fusion processes.

Sincerely,

Gary S. Collins

Gary S. Collins
Associate Professor of Physics

Phone: (509) 335-1354
Bitnet: Collins@WSUVMS1

SUMMARY OF PAST AND PRESENT RESEARCH ON COLD FUSION

Gary S. Collins

Department of Physics
Washington State University
Pullman, Washington 99164-2814

(509) 335-1354

September 20, 1989

(Submitted to the Energy Research Advisory Board, DOE)

This report describes activities of myself and my coworkers at Washington State University from April to the present. Two speculative theories of new types of fusion processes were developed by a group of faculty in the Physics Department. Fleischmann-Pons experiments with a group of students are just now beginning. Related experiments are also summarized.

FUSION THEORIES

1. *Neutron Tunneling Between Neighboring ^{6}Li Nuclei in Solids*, by Gary S. Collins, John W. Norbury, Gerald E. Tripard and James S. Walker (original version dated April 16; the attached version dated May 18; unpublished).

We proposed that Li atoms may become concentrated electrochemically within metal cathodes in Fleischmann-Pons type experiments, and that neutrons may tunnel between ^{6}Li nuclei. Nuclear criteria identified as important for the tunneling mechanism are a large neutron capture crosssection, a small neutron separation energy and large Fermi motion energy fluctuations of neutrons in the nucleus. All three criteria are satisfied by ^{6}Li. There are two principal reactions:

$$^6\text{Li} + {}^6\text{Li} \rightarrow {}^7\text{Li} + p + \alpha \qquad (Q = 3.550\ \text{MeV}),\ \text{and} \qquad (1)$$

$$^6\text{Li} + {}^6\text{Li} \rightarrow \alpha + t + p + \alpha \qquad (Q = 1.082\ \text{MeV}). \qquad (2)$$

Depending on the branching ratio, there could be "clean fusion" or copious production of tritium. Predictions of the theory are that:

i. Enthalpy generation should be proportional to the ^{6}Li isotopic abundance *squared*. For pure ^{6}Li, it should be enhanced by a factor of 180.
ii. Enthalpy generation should be insensitive to use of H_2O, D_2O or T_2O.
iii. Reaction products should include large quantities of ^{4}He and, possibly, tritium.

2. *Deuteron Tunneling at Electron-Volt Energies*, by Gary S. Collins, John W. Norbury and James S. Walker (original version April 29; later version presented as a poster paper at the Workshop on Cold Fusion, Santa Fe; the attached copy will appear in the Proceedings of the Workshop).

We proposed a new mechanism for d-d tunneling and fusion made possible by high densities of atomic or conduction electrons at nuclear sites in cold fusion experiments, unlike in accelerator experiments. It is proposed that the ground state or 20.1 MeV 0^+ state of ^{4}He can be created from the combined d+d state by an electron-conversion process, in which the excess energy of the 23.84 MeV combined state is given to an electron. There are two reactions:

$$d + d + e^- \rightarrow {}^4\text{He (g.s.)} + e^- \text{ (K=23.8 MeV), and} \tag{3}$$

$$d + d + e^- \rightarrow {}^4\text{He (20.1 MeV state)} + e^- \text{ (K= 3.7 MeV),} \tag{4}$$

with the second reaction followed only by

$${}^4\text{He (20.1 MeV state)} \rightarrow t \text{ (K= 0.08 MeV)} + p \text{ (K= 0.23 MeV).} \tag{5}$$

Assuming that conversion probabilities vary as for the L=0 internal conversion process, The branching ratio would be 99% for reaction (4), followed by reaction (5). The theory predicts copious production of tritium, energetic electrons and Bremmsstrahlung, but no neutrons.

FLEISCHMANN-PONS EXPERIMENTS

To test predictions of the above theories, FP type experiments were attempted beginning at the time of the Workshop. Following discussions at the Workshop, we decided to carry out experiments using closed cells in order to (1) allow reaction products such as He to build up over time to high concentrations, and to (2) eliminate uncertainties that partial recombination of gasses might be taking place within the cell or that enthalpy might be carried off by evolving gasses. We have expended much effort up to the present time to build closed cells using the idea presented by M. E. Hayden et al., University of British Columbia at the Workshop. In Hayden's design, a Pd metal catalyst is used to recombine the D_2 and O_2 gasses within the cell. According to Hayden, the catalyst could initially be heated to "activate" the surface, and the heating source later be turned off.

We found that design of a closed cell able to operate for weeks at varying power levels was not trivial. Self-heating of the catalyst to a visible glow appears essential for stable operation. The catalyst tends to stop working at low currents when the glow cannot be sustained. The catalysts also do not work well above 40-50 °C, presumably due to high water vapor pressure and surface coverage. Other catalysts were studied, but we found Pd to work better than Pt, Pt black or Rh. Our design, now optimized, uses a funnel like Hayden's. The funnel is positioned with its lower edge immersed in the electrolyte, so that mostly H_2 gas is collected inside the funnel and mostly O_2 gas outside. A stream of H_2 gas is directed from the orifice of the funnelonto a Pd filament strip made by flattenning a 0.25 mm diameter Pd wire. Finally, our cells have been constructed of teflon to avoid leaching wall materials into the electrolyte.

Closed-cell experiments will begin soon using 0.32 cm diameter by 1.2 cm long Pd rods as cathodes. We will observe the following:

(1) Enthalpy generation. Heat output will be measured using a flowing-water calorimeter capable of resolving enthalpy generation with 1% precision at cell powers of 10 W.

(2) Gamma-ray emissions. Gamma spectra will be continuously recorded using 5 x 5 cm NaI scintillators, enabling a search for radiation from neutron capture in the NaI crystals or in absorber sheets like Cd.

(3) Reaction products. Once there are any indications of anomalous cell activity or gamma production, samples of the electrolyte and gas in the cell will be analysed for tritium and helium isotopes.

This experimental work is being carried out with the assistance of graduate student Steven Parry, several undergraduates, and support for supplies from WSU's Research Office.

OTHER EXPERIMENTS

Concentration of Li in metal cathodes. At the Workshop, I reported observations which suggest that Li may be concentrated in/on cathodes: After electrolysis using a Pt (not Pd!) cathode and LiOH electrolyte for 24 hours, current was cut and the Pt was immediately immersed in liquid nitrogen. Color changes from silvery metallic to yellow-brown to black were observed within 2 minutes which suggested that the surface was reacting chemically at 77 K. As a possible explanation, we suggested that Li might be concentrating in/on the samples, and reacting (with nitrogen?) after cutting the cell potential. Subsequent to the workshop, neutron activation analysis carried out at WSU on the Pt cathodes confirmed the presence of ^{7}Li in the range 1-10 atomic %. These experiments were carried out with graduate students Steven Shropshire and Jiawen Fan, and minor support from the National Science Foundation under grant DMR 86-19688 (Metallurgy Program).

Atomic-scale studies of vacancy defects in Pd. In my talk at the Workshop, I speculated that fusion reactions might take place within lattice vacancies in the Pd cathodes. A search was made to detect trapping of mobile vacancy defects at ^{111}In probe atoms in Pd metal. Two complexes were observed to form with ^{111}In probes during annealing near 300 K using the technique of perturbed γ-γ angular correlations. The first, with a coupling frequency $\omega_Q = 79$ Mrad/s, is identified from other work as due to a trapped monovacancy. The second, observed for the first time in this study, with $\omega_Q = 167$ Mrad/s, is possibly due to a trapped divacancy. Partly because of poor signal-to-noise ratios, experiments have not yet been carried out to decorate the vacancy clusters with hydrogen atoms. These experiments were carried out with physics senior Phillip Himmer and support of the National Science Foundation under a REU supplement to grant DMR 86-19688 (Metallurgy Program).

NEUTRON TUNNELING BETWEEN NEIGHBORING ^{6}Li NUCLEI IN SOLIDS

Gary S. Collins, John W. Norbury, Gerald E. Tripard, and James S. Walker

Department of Physics, Washington State University, Pullman, WA

99164-2814

May 18, 1989

PACS-88 numbers: 25.70.Jj, 66.30.Jt, 82.45.+z

ABSTRACT

As a possible explanation of recent reports by Fleischmann, Pons and Hawkins and by Jones et al. of nuclear reactions taking place in electrochemically charged metals, it is proposed that Li becomes concentrated in the metals by electrochemical forces and that neutrons tunnel quantum-mechanically between neighboring ^{6}Li nuclei. Nuclear criteria leading to this behavior include a large neutron capture cross-section, a small neutron separation energy, and large Fermi motion energy fluctuations of neutrons in the nucleus.

Recent reports of nuclear fusion taking place in hydride-forming metals at ambient temperature are of great interest.[1,2] Common features of these two experiments are as follows:

1. Possible fusion reactions occur in or on hydride-forming metals, such as Pd.
2. Evidence of fusion was detected in electrochemical cells, with Pd as a cathode.
3. Li was a cation impurity in electrolytes of both experiments.[1,2]
4. Small numbers of neutrons were observed to be emitted from the cells, strongly suggesting that nuclear reactions are involved.

However, neutron emission rates reported[1] by Fleischmann, Pons and Hawkins (FPH) were about 10^8 times smaller than expected from the observed enthalpy generation, assuming the principal reactions were $d+d \rightarrow {}^3He+n$ and $d+d \rightarrow t+p$.[3] Therefore, operative reactions have been a mystery.

In this letter, we examine the possibility that Li is involved in the principal reaction mechanisms. We propose that neutrons tunnel between ${}^6Li$ nuclei, thereby avoiding the necessity to overcome the huge Coulomb barriers associated with charged particles.[4]

We argue that ${}^6Li$ and ${}^7Li$ atoms are concentrated electrochemically in/on the cathode in much the same way as are H or D atoms, as follows:

1. By use of a strongly basic electrolyte, LiOD, FPH[1] made Li^+ the principal positive-ion species in solution. Indeed, 0.1 M LiOD in D_2O leads to ion molarities of ~0.1 M Li^+ and ~10^{-13} M D^+. Therefore, the electrochemical ion current could well contain a contribution from Li^+. The fact that Jones et al.[2] observed lower fusion reaction rates might be caused by their use of an acidic solution.
2. With a radius of 0.68 Å, the Li^+ ion is small, indicating that electrodeposition and subsequent diffusion similar to hydrogen might be expected. Li might deposit as a surface layer and/or diffuse into the lattice like H, although more slowly.

3. To understand the long "incubation" times, of weeks, reported by FPH prior to observing energy generation, we propose that Li must be concentrated in/on the cathode in order for reactions to commence.[5]

4. Direct evidence for Li concentration in/on Pt cathodes comes from preliminary experiments carried out at Washington State University:[6] (a) the pH of a 1 M LiOH solution decreased from ~14 by 4 units during electrolysis over 24 hours at a current density of 20 mA/cm^2. (b) Within minutes following 24-hour electrolyses using Pt cathodes and 1 M or 0.1 M LiOH electrolytes, and after prompt immersion in liquid nitrogen, the cathode surfaces were observed to become discolored, turning first brown and then black. To explain these remarkable color changes, we can only conceive of a chemical reaction involving Li, such as oxidation or nitridation.

The nuclear properties of ^{6}Li are unusual. It is useful to consider it as a loose union of a deuteron and an α-particle,[7] with a binding energy of only 1.475 MeV (see fig. 1). This leads to unusual properties in $^6\mathrm{Li}+{}^6\mathrm{Li}$ scattering.[8] Also, ^{6}Li has a large thermal neutron capture cross-section, $\sigma_c(n,\alpha) = 942$ b.[9] The separation energy of the least bound neutron in ^{6}Li, calculated from $^6\mathrm{Li} \rightarrow \alpha + d$ and $d \rightarrow p + n$, is 3.700 MeV, a relatively low value.

In light of the large neutron capture cross-section and weak neutron binding of ^{6}Li, we propose that a neutron from one ^{6}Li tunnels to a neighboring ^{6}Li in the condensed state, thereby avoiding the Coulomb barrier. There are two principal reactions:

$$^6\mathrm{Li} + {}^6\mathrm{Li} \rightarrow {}^7\mathrm{Li} + p + \alpha \quad (Q = 3.550\ \mathrm{MeV}),\ \text{and} \tag{1}$$

$$^6\mathrm{Li} + {}^6\mathrm{Li} \rightarrow \alpha + t + p + \alpha \quad (Q = 1.082\ \mathrm{MeV}). \tag{2}$$

There is already substantial evidence of sub-Coulomb tunneling processes occurring between nuclei separated by distances much larger than the nuclear radius. Neutron tunneling and proton tunneling were first proposed by Breit and Ebel[10] as mechanisms to explain cross sections observed by Reynolds and Zucker[11] for the reactions $^{14}N(^{14}N,^{13}N)^{15}N$ and $^{14}N(^{14}N,^{13}C)^{15}O$. As a second example, May and Clayton[12] suggested neutron tunneling as a mechanism in the astrophysically important reaction $^{3}He(^{3}He,2p)^{4}He$, which is relevant to the ^{8}B solar neutrino flux. They emphasized that neutron tunneling can be the dominant process at energies below the Coulomb barrier when projectile and target nuclei are separated by large distances.

Depending on the branching ratio between the two reactions, neutron tunneling between ^{6}Li nuclei could lead to clean fusion or copious production of tritium. No free neutron emission is expected, however. While the average binding energy of the least-bound neutron is 3.700 MeV, fluctuations in the kinetic energy of this neutron will occur due to Fermi motion. As shown schematically in fig.2, the instantaneous energy of the neutron may fluctuate with a probability distribution $P_n(E)$ about the separation energy E_{sep}. At times, therefore, the neutron's effective binding energy may approach zero, leading to strong enhancement of the tunneling probability. The fact that the reacting species remain at ~1 Å separations for very long times, on a nuclear time-scale, ensures that even very infrequent energy fluctuations up to zero energy can lead to tunneling. This concept, of course, also suggests the possibility of neutron tunneling between deuterons or other nuclei. As for the deuteron, however, in spite of its lower neutron separation energy, 2.224 MeV, we believe that the neutron's Fermi motion should be much smaller because it has only one other nucleon with which to share energy.

If these ^{6}Li reactions were to occur in electrochemical cells, then there should be energetic collisions of reaction products with hydrogen (p or d). The collisions may induce secondary nuclear reactions, which could account for the small quantities of neutrons observed in the experiments.[1,2] In addition, there is the possibility of neutrons tunneling between deuterons. Such tunneling, however, would lead only to $d+d \rightarrow t+p$, and not produce neutrons.

Three simple experimental tests of the ^{6}Li neutron tunneling process are proposed.

1. Enthalpy generation should depend on the probability of having two ^{6}Li nuclei in close proximity. Since normal abundance of ^{6}Li is 7.5%,[8], use of pure ^{6}Li should lead to enhanced enthalpy generation by a factor of $(100/7.5)^2 = 180$.
2. Enthalpy generation should be insensitive to use of H_2O, D_2O, or T_2O based electrolytes.
3. Reaction products should include large quantities of ^{4}He and, possibly, tritium.

To summarize, we examined the possibility of neutron tunneling between neighboring ^{6}Li nuclei in the context of recent experimental reports of cold nuclear fusion. The neutron tunneling mechanism can explain some of the observations connected with cold fusion, in particular small neutron production rates. However, our examination has been limited: we have not calculated how the reaction rate should vary with distance between ^{6}Li nuclei; in addition, detailed information about the distribution of ^{6}Li-^{6}Li distances in the cathodes is unavailable. If one assumes that a high density of Li atoms constitutes a solid-state criterion for tunneling, then other materials in which neutron tunneling might be observed include LiD, LiH, LiF or Li metal.

We acknowledge useful discussions with Royston Filby, Phillip Rosenberg and Chino Srinivasan, and the assistance of Gayle Norbury and Steven Shropshire.

---

1. *Electrochemically Induced Nuclear Fusion of Deuterium*, Martin Fleischmann, Stanley Pons and M. Hawkins, J. Electroanalytical Chemistry 261, 301 (1989), and erratum.
2. *Observation of Cold Nuclear Fusion in Condensed Matter*, S. E. Jones, E. P. Palmer, J. B. Czirr, D. L. Decker, G. L. Jansen, J. M. Thorne, S. F. Taylor and J. Rafelski (accepted for publication in Nature.)
3. Standard abbreviations are used for nuclei: $p = {}^1H$, $d = {}^2H$, $t = {}^3H$, $\alpha = {}^4He$, and n = neutron.

4. We realize that other neutron tunneling reactions such as d+d → t+p or d+ ^{6}Li → p + ^{7}Li are possible. However, because of the unusual nuclear properties of ^{6}Li, in the present letter we examine especially the possibility of neutron tunneling occuring only via ^{6}Li + ^{6}Li.
5. To our knowledge there is no data on Li diffusion in Pd, or, for that matter, most metals. However, rapid diffusion of Li in semiconductors is familiar with regard to Ge(Li) and Si(Li) radiation detectors, which must be continuously kept at cryogenic temperatures to avoid out-diffusion of Li from the lattice.

6. Gary S. Collins, Steven L. Shropshire and Jiawen Fan (to be published).
7. See, for example, H. H. Gutbrod, H. Yoshida and R. Bock, in Nuclear Reactions Induced by Heavy Ions, ed. R. Bock, W. R. Hering (North-Holland, Amsterdam 1970), p. 311.
8. H. T. Fortune, G. C. Morrison and R. H. Siemssen, Phys. Rev. C3, 2133 (1971).
9. Table of Isotopes, ed. C. M. Lederer and V. S. Shirley (John Wiley, New York, 1978, 2nd edition.)
10. G. Breit and M. E. Ebel, Phys. Rev. 103, 679 (1956).
11. H. L. Reynolds and A. Zucker, Phys. Rev. 101, 166 (1956).
12. R. M. May and D. D. Clayton, Astrophys. J. 153, 855 (1968).

Figure Captions

Figure 1. Schematic interaction between two ^{6}Li nuclei in terms of the $\alpha + d$ model of nuclear structure.

Figure 2. Energy diagram of the least-bound neutrons in ^{6}Li nuclear potential wells, schematically showing the probability distribution of the neutron energy about the mean separation energy E_{sep}.

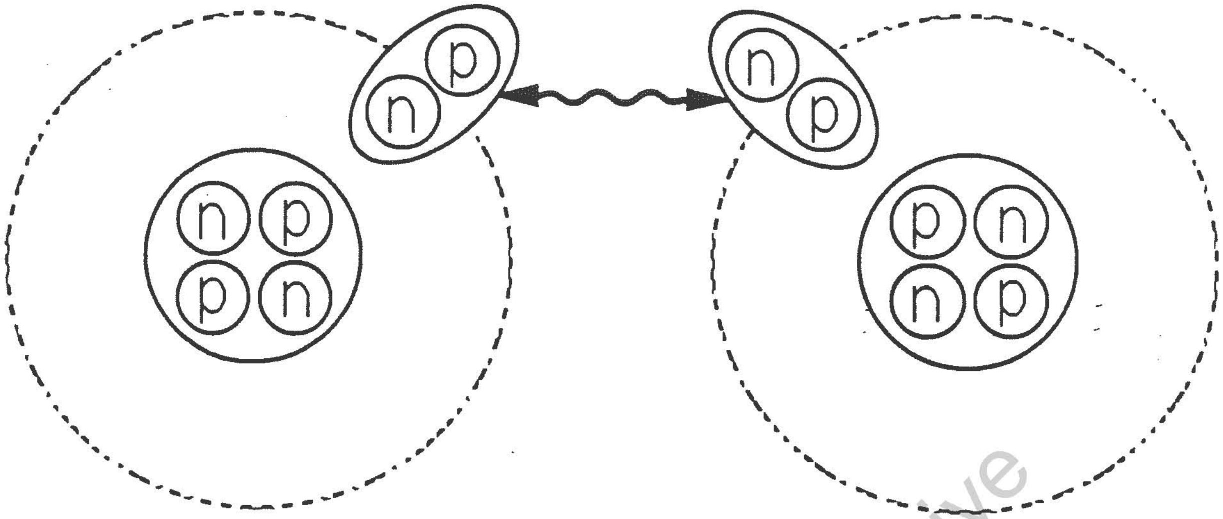

Figure 1.

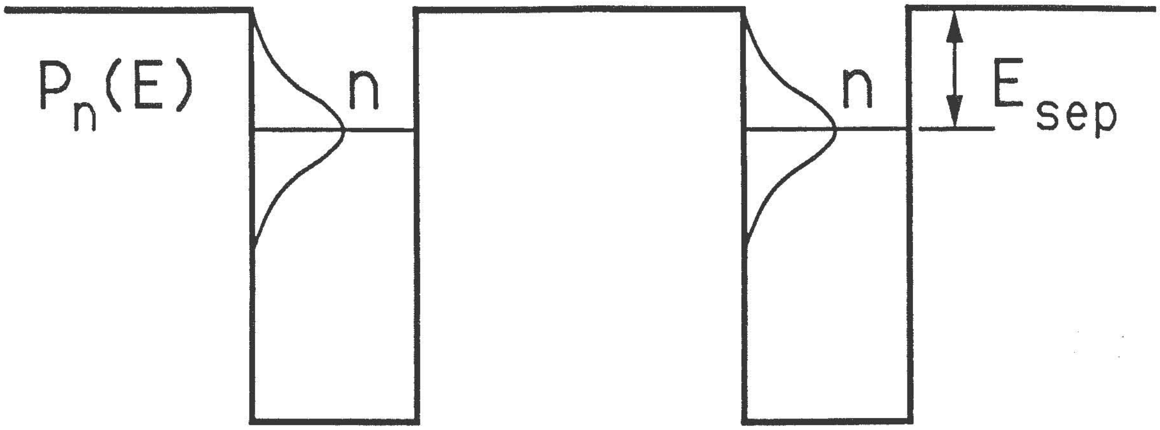

Figure 2.

Workshop on Cold Fusion, Santa Fe, NM, May 23-25, 1989

DEUTERON TUNNELING AT ELECTRON-VOLT ENERGIES

Gary S. Collins and James S. Walker
Department of Physics, Washington State University, Pullman, WA 99164-2814
and
John W. Norbury
Department of Physics, Washington State University, Pullman, WA 99164-2814, and
Department of Mathematics and Physics, Rider College, Lawrenceville, NJ 08648

ABSTRACT

We speculate on a new mechanism for deuteron-deuteron fusion reactions at electron-volt energies. Appealing to conservation principles, it is shown that deuteron tunneling leading to fusion is very unlikely to take place between two isolated deuterons. It is argued that in solids, however, tunneling may lead to fusion via a new reaction mechanism which populates energy levels of ^{4}He, with simultaneous energy transfer to an electron. Predictions of this theory are that $d+d+e^-$ fusion at electron-volt energies in solids should lead to copious production of tritium, protium, energetic electrons, and small quantities of ^{4}He.

Recent reports of possible nuclear fusion taking place in metal electrodes at ambient temperatures,[1,2] known as "cold nuclear fusion,"[2] have been discussed in terms of the following fusion reactions:[3]

$$d + d \rightarrow t + p \qquad (Q = 4.0 \text{ MeV}) \qquad (1)$$

$$d + d \rightarrow {}^{3}He + n \qquad (Q = 3.3 \text{ MeV}) \qquad (2)$$

$$d + d \rightarrow {}^{4}He + \gamma \qquad (Q = 23.8 \text{ MeV}), \qquad (3)$$

with branching ratios of approximately 50%, 50% and 0%, respectively.[4] However, observed neutron emission rates are $\sim 10^7$ times smaller than expected from the reported levels of energy generation,[1] assuming that the above branching ratios should apply.

It is the purpose of this letter to examine deuteron tunneling at electron-volt energies. We find that d-d tunneling at electron-volt energies cannot occur via any of the above two-body reactions. This conclusion is valid in the approximation that only S-wave interactions are important at these low energies.

There is already substantial evidence of sub-Coulomb tunneling processes occurring between nuclei separated by distances which are much larger than the nuclear radius. Neutron and proton tunneling was first proposed by Breit and Ebel[5] as a mechanism to explain cross sections observed by Reynolds and Zucker[6] for the reactions ${}^{14}N({}^{14}N,{}^{13}N){}^{15}N$ and ${}^{14}N({}^{14}N,{}^{13}C){}^{15}O$. As a second example, May and Clayton[7] have suggested neutron tunneling as a mechanism in the astrophysically important reaction ${}^{3}He({}^{3}He,2p){}^{4}He$, which is relevant to the ${}^{8}B$ solar neutrino flux. They emphasized that neutron tunneling can be the dominant process at energies below the Coulomb barrier when projectile and target nuclei are separated by large distances. In a separate communication,[8] we examine the possibility that neutron tunneling might take place between neighboring ${}^{6}Li$ nuclei in solids; criteria conducive to this process are a large thermal neutron capture cross section, a small neutron separation energy, and large fluctuations of the energy of the least-bound neutron which are caused by Fermi motion. The first and third criteria are not satisfied for deuterons, so that the situation is fundamentally different for d + d fusion.

Tunneling in d + d reactions can in principle take place via deuteron tunneling through the Coulomb barrier,[9] via neutron tunneling through the nuclear potential barrier, or via proton tunneling through both the Coulomb and nuclear barriers. The Coulomb barrier for the deuteron process is ~0.4 MeV high, whereas neutron tunneling involves penetration of a barrier of 2.2 MeV (the binding energy of the deuteron). Proton tunneling would involve penetrating the Coulomb barrier as well as the 2.2 MeV barrier. Since the tunneling probability is a strong function of the product of barrier height and width, we conclude that deuteron tunneling is by far the most likely process to occur.

At low incident energies, conservation of angular momentum and parity in d-d fusion reactions leads to different final states than at higher energies. Since the deBroglie wavelength of a thermal deuteron is of order 0.2 Å, much larger than the size of a deuteron, only S-wave interactions between deuterons should be important. As a consequence, the conservation laws require that any combined d + d state of spin $I = 1^+$ deuterons should have total angular momentum and parity $J^\pi = 0^+$ or 2^+.

When a deuteron with bombarding energy of the order of electron-volts tunnels, it can lead either to a direct reaction with particle emission or to formation of an excited intermediate state of a ^{4}He nucleus, with an excitation of 23.847 MeV.[10] However, neither of these is possible here, as follows: The cross sections for direct reactions leading to n or p emission approach zero at 23.847 MeV;[11] There are no positive-parity resonances close to 23.8 MeV (see figure 1).[11,12] Thus, it appears to be impossible for tunnelling of thermal deuterons to lead to fusion.

Accepting recent claims that nuclear fusion does take place in condensed matter at ambient temperatures, however, we are led to consider novel reaction mechanisms. Specifically, we propose a mechanism by which states of ^{4}He below 23.847 MeV might become populated even though there may be negligible overlap between the 23.8 MeV excitation energy and states of ^{4}He. Examination of figure 1 shows that there are no low-lying 1^+ or 2^+ states of ^{4}He, from which we conclude that only the combined d+d $J^\pi = 0^+$ state can lead to fusion.[13] Considering first γ-ray processes, excited states of ^{4}He should only be populated directly by simultaneous creation of a photon, as in p(n,γ)d. However, selection rules forbid photon creation when the initial and final nuclear states both have spin zero, as is the case for the ground and first two excited nuclear states of ^{4}He. Direct population of the only other accessible nuclear level, the $I = 2^-$ state at 22.1 MeV, would require an M2 transition with energy 1.7 MeV. We consider this process to be improbable owing to the high multipolarity; however, observation of 1.7 MeV γ-rays would be of great significance. With the exception of this improbable M2 transition, and ignoring P-wave interactions, we conclude that two-body d+d fusion reactions cannot occur at electron-volt energies. It therefore is not clear how cold fusion of deuterons might occur.

In our opinion, resolution of this mystery lies in the condensed-matter environment of the deuterons, and specifically in the presence of a high density of atomic or conduction electrons at the deuterons' locations. By contrast, in accelerator experiments all nearby electrons are likely to be ionized or excited to high-energy atomic or molecular states by impulsive Coulomb forces produced during approach of the projectile nucleus, so that electron densities at the nuclear sites can be expected to be very small compared with 1s electron densities.

We propose the following electron-conversion reactions:

$$d + d + e^- \rightarrow {}^4\text{He (ground state)} + e^- \; (K = 23.84 \text{ MeV}), \qquad (4)$$

$$d + d + e^- \rightarrow {}^4\text{He (20.1 MeV state)} + e^- (K= 3.7\ \text{MeV}), \qquad (5)$$

with the second reaction followed only by[11]

$${}^4\text{He (20.1 MeV state)} \rightarrow t\ (K= 0.08\ \text{MeV}) + p\ (K= 0.23\ \text{MeV}) \qquad (6)$$

because the 20.1 MeV excitation is below the threshold for neutron emission. There is obvious similarity between reactions (4) and (5) and internal conversion processes between $I= 0$ states (see, e.g., ref. 4), although here the initial, combined $d+d$ state is not a nuclear eigenstate. Conceptually, the tunneling and electron-conversion processes may be thought of as taking place simultaneously. Assuming that the electron conversion probabilities vary here as $\Delta E^{-5/2}$, in the same way as for internal conversion of $L=0$ multipolar transitions,[14] branching probabilities of reactions (4) and (5) should be 0.97% and 99.03%, respectively. Thus reactions (5) and (6) may dominate, leading to copious production of tritium, protium, energetic electrons, and, via reaction (4), lesser amounts of ^{4}He may be produced.[15]

At present there are only limited experimental data in the literature with which to compare predictions from these $d+d+e^-$ reactions. Observations of very small numbers of neutrons in reference 1, when compared with energy production, is consistent with our reactions. The neutrons could be produced by secondary reactions between energetic particles in the electrodes, leading to conventional nuclear fusion. Neutrons would also be produced via the weak M2 transition to the 22.1 MeV level, since the 22.1 MeV level decays via neutron or proton emission.[11] The most direct test of our reactions would come from measurements of emissions of electrons with energies of 3.7 or 23.8 MeV. Such measurements will be complicated by energy losses in materials.

We are happy to acknowledge conversations with Gerald E. Tripard and George Hinman and the assistance of Gayle Norbury, Steven Shropshire and Phillip Himmer.

---

[1] M. Fleischmann, S. Pons and M. Hawkins, J. Electroanal. Chem. 261, 301 (1989), and erratum.

[2] S. E. Jones, E. P. Palmer, J. B. Czirr, D. L. Decker, G. L. Jensen, J. M. Thorne, S. F. Taylor and J. Rafelski, Nature 338, 737 (1989).

[3] Abbreviations used are: $p = {}^{1}H$, $d = {}^{2}H$, $t = {}^{3}H$, $n =$ neutron, $e =$ electron, and $K =$ kinetic energy.

[4] Introductory Nuclear Physics, K. S. Krane (John Wiley, New York, 1988).

[5] G. Breit and M. E. Ebel, Phys. Rev. 103, 679 (1956).

[6] H. L. Reynolds and A. Zucker, Phys. Rev. 101, 166 (1956).

[7] R. M. May and D. D. Clayton, Astrophys. J. 153, 855 (1968).

[8] G. S. Collins, J. W. Norbury, G. E. Tripard and J. S. Walker (submitted to Physical Review Letters; received April 17, 1989.)

[9] C. DeW. Van Siclen and S. E. Jones, J. Phys. G: Nucl Phys. 12, 213 (1986).

[10] We ignore elastic d-d scattering because it does not lead to energy release.

[11] S. Fiarman and W. E. Meyerhof, Nucl. Phys. A206, 1 (1973).

[12] The angular momentum of the state at 25.5 MeV is uncertain, and that state is ignored in our analysis (see ref. 11.)

[13] Thinking heuristically of tunneling as a scattering process, this means that the reaction can take place only when the deuterons' spins are opposed. Tunneling with $J^{\pi} = 2$ would lead to no reaction.

[14] To compare the transition probabilities for electron-conversion to different $I = 0$ states, we use the energy dependence of the internal conversion coefficient $\alpha(E0)$ from reference 3, equation 10.26.

[15] If these $d + d + e^{-}$ tunneling reactions produce the energy production reported in ref. 1, then there will be significant radiation hazards from energetic electrons and radioactive tritium.

FIGURE CAPTION

Figure 1. Level diagram of ^{4}He, with angular momenta and parities at left and energies, in MeV, at right. The dashed line indicates the 23.8 MeV excitation energy of the reaction $d + d \rightarrow {}^4$He, and does not represent a state of ^{4}He.

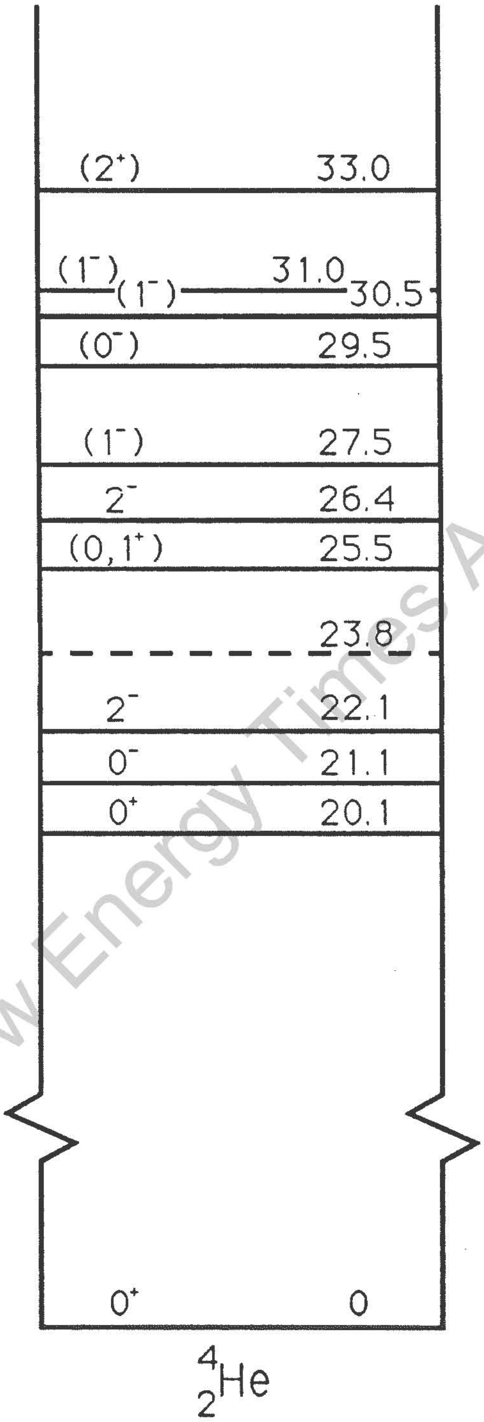
(2⁺) 33.0
(1⁻) 31.0
(1⁻) 30.5
(0⁻) 29.5
(1⁻) 27.5
2⁻ 26.4
(0,1⁺) 25.5
23.8
2⁻ 22.1
0⁻ 21.1
0⁺ 20.1
0⁺ 0
$^4_2$He

Figure 1.

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

(516) 282
FTS 666 2772

Office of the Director

September 21, 1989

Dr. John R. Huizenga
Co-Chairman, Cold Fusion Panel
Energy Research Advisory Board
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear John:

I am enclosing an additional response to your cold fusion request which should be incorporated into Brookhaven's package. This material was received in my office yesterday, September 20. I hope this does not cause any inconvenience to you.

Sincerely,

Nick

N. P. Samios
Director

Enclosure

MATERIALS USED IN COLD FUSION EXPERIMENTS

PRINCIPAL INVESTIGATOR:

Dr. Min Chen, Professor of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts

ORGANIZATION:

Massachusetts Institute of Technology and Brookhaven National Laboratory

SHORT DESCRIPTION OF TYPE OF EXPERIMENT:

Measurements of Neutron Emission Induced by Muons Stopped in Metal Deuteride Targets

RESULTS AND COMMENTS:

An 80 MeV/c negative muon beam from the Alternating Gradient Synchrotron at Brookhaven National Laboratory was used to investigate the stopping of muons inside Pd, Ti and Y targets saturated with deuterium. Neutron emission from the targets was measured with an array of ^{3}He detectors, and in some runs, the temperature of the target was monitored as a function of time, with and without a flux of muons on the target. The neutron rates were also measured for Pd cathodes in an active electrochemical cell similar in design to those used in so-called "cold fusion" experiments, and the electrolyte solution was analyzed for excess tritium. No evidence was found for muon catalyzed fusion at rates consistent with those claimed in "cold fusion" experiments. Neutron production from catalyzed fusion due to the presence of deuterium in palladium deuteride, $PdD_{0.7}$, exposed to muons was determined to be 0.0 ± 0.03 (stat.) ± 0.25 (syst.) neutrons per stopped muon.

I. MATERIALS USED FOR ELECTROCHEMICAL EXPERIMENTS (please complete one sheet for each experiment)

	CATHODES	ANODES (Corresponding)
MATERIAL	Palladium	Platinum Laboratory
PURITY	Research and investment	Grade Wire
ALLOYING ELEMENTS	Impurities only	Unprocessed
SOURCE OF MATERIAL	Swiss Bank Corporation and Johnson Mathey	

PREPARATION	
CAST OR WROUGHT	Both
ANNEALED	Yes and no
ATMOSPHERE	Yes and no
VACUUM	Yes and no
SPECIAL TREATMENT	Yes and no
CHARACTERIZATION	
STRUCTURAL	Yes
CHEMICAL	Yes
BEFORE OR AFTER USE	Both
METHODS	
RESULTS	

No catalyzed fusion neutron production

NOTABLE OBSERVATIONS

No unknown nuclear or chemical reaction

D / METAL RATIO ATTAINED ≃ 0.7

EXPERIMENT YIELDED HEAT	------yes	--x---no
NEUTRONS	------yes	--x---no
TRITIUM	------yes	--x---no
HELIUM	------yes	--x---no

II. MATERIALS USED FOR GASEOUS CHARGING EXPERIMENTS (please complete one sheet for each experiment)

MATERIAL Palladium, titanium, yttrium, and vanadium

PURITY Research grade

ALLOYING ELEMENTS Impurities only

SOURCE OF MATERIAL Research/Brookhaven National Laboratory

PREPARATION See attached paper
CAST OR WROUGHT
ANNEALED
ATMOSPHERE
VACUUM
SPECIAL TREATMENT

CHARACTERIZATION
STRUCTURAL
CHEMICAL -
BEFORE OR AFTER USE
METHODS
RESULTS

No catalyzed fusion neutron production

NOTABLE OBSERVATIONS

No unknown chemical or nuclear reactions

D / METAL RATIO ATTAINED see attached paper

EXPERIMENT YIELDED HEAT	______yes	__x___no
NEUTRONS	______yes	__x___no
TRITIUM	______yes	__x___no
HELIUM	______yes	__x___no

University of Illinois
at Urbana-Champaign

**Department of
Nuclear Engineering**

214 Nuclear Engineering
Laboratory
103 South Goodwin Avenue
Urbana, IL 61801-2984

Fusion Studies Laboratory

217 333-3772

September 22, 1989

Mr. John R. Huizenga
Co-Chairman, ERAB
Panel on Cold Fusion
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D. C. 20585

Re: Your letters of July 20 and August 9

Dear Mr. Huizenga:

In response to your letter of July 20, I would like to summarize the research that was carried out in the Fusion Studies Laboratory on cold fusion. We have attempted two types of experiments. The first was a simple electrolytic cell of the Pons-Fleischmann type (the details of this cell are described in the attached summary submitted as a response to your letter of 8/9/89). Since we were unable to obtain positive experiments with this cell and did not have explicit funding for the work, we decided to mothball the experiment in late July. We now have some thoughts about alternate cell designs and are tentatively considering starting new experiments this fall.

The second experiment that we attempted was the use of plasma implantation in a palladium rod. This experiment is described in the attached reprint (D. N. Ruzic, et al., "A Novel Apparatus to Investigate the Possibility of Plasma-Assisted Cold Fusion"). Since positive results were not obtained with this experiment, it too has been mothballed pending further decisions.

The other effort in the Fusion Studies Laboratory has concentrated on select theoretical studies. Most of the work has focused on the possible role of the Oppenheimer-Phillips reaction and a preliminary presentation was presented at the Santa Fe meeting, along with the enclosed reprint (M. Ragheb and G. Miley, "On the Possibility of Deuteron Disintegration in Electrochemically Compressed D^+ in a Palladium Cathode"). We are continuing work on this theory with emphasis on two aspects: 1) An explanation of the tritium rates observed in the experiments and 2) incorporate it with a collective plasma model to explain high reaction rates.

In conclusion, we have not obtained definitive experimental results to date. However our general view is that there are some very important physical mechanisms that are being observed in a variety of experiments reported by others. Thus we hope to be able to maintain a low level combined experimental/theoretical program in this area.

In general, we would agree with the interim report conclusion that useful sources of energy will result from this discovery but that there remain unresolved issues and scientifically interesting questions. Based on this, however, we draw a quite different conclusion about what should be done relative to future support. Our view is that the "unresolved issues and scientific questions" i.e., the basic physics deserves a low level but broad research support as opposed to restricting funding to "current programs." This will greatly diminish the important growth of interdisciplinary efforts in this area that are outside of the established programs and in our view is just the wrong thing to do. If you require any additional information, please write or call: Telephone (217) 333-3772; Fax: (217) 333-2906.

Sincerely,

George H Miley

George H. Miley, Director
Fusion Studies Laboratory

GHM:cs

Enclosures

P. S. Also, you may be interested to note that Fusion Technology, which has an editorial office in the Fusion Studies Laboratory, is running reviewed Technical Notes on cold fusion. Thus far, ten have been published and 12 are pending.

SUMMARY OF ELECTROLYTIC EXPERIMENT IN FUSION STUDIES LABORATORY
cf ERAB Letter of 08/09/89

1.	Source of D_2O:	Analytical grade 100 gm buffled D_2O.
	Specific activity:	Not measured.
2.	Additive:	LiOH
3.	Electrolytic cell:	2-inch diameter thick-walled test tube containing the electrode holders; the cathode was made of 2cm x 5cm x 1cm Pd strip folded into an annulus of length 2cm and diameter obtainable with 5cm circumference. The Pd strip was coated with Pd black by electrolysis of 5% PdCls solution. The anode was a warmed Pt wire kept around a glass rod cage, at about a cm from the cathode on the outer side. The D_2O cell was not entirely sealed to air. But the cell was nearly sealed and kept either in a water bath or in a homemade calorimeter in a constant temperature bath. The electrodes were connected by Pt wire which in turn was connected to copper wires outside the cell and hooked to the power supply.
4.	Operating Conditions:	Continuously operated for 3 to 4 days at a stretch; total run time of 3 weeks; voltage was about 15V; current was about 1.75 amp. Cell critical voltages at which the current increases rapidly was measured to be about 1.7-2.0V.
5.	Schedule of D_2O Additions:	About 15ml pure D_2O was added once a day to maintain the fluid level.
6.	Neutron Production:	Was monitored with a calibrated BF_3 counter and multichannel analyzer. No significant neutron production above the background rate of 6 to 7 counts per minute was measured.
7.	Tritium Content:	Was tested by comparing the scintillation counts of electrolyzed D_2O and control volume of pure analytical grade D_2O, each measuring about 10ml. Though the scintillation

count of the electrolytic cell D_2O was slightly above that of the control D_2O, the result was not deemed to be significant. The slight excess amount was assessed to be due to concentration of tritium by the electrolysis rather than added production.

8. Calorimetric measurements: Were tried with the electrolysis cell immerced in a water bath contained in a Dewar flask, which in turn was kept in a constant temperature bath at around 25 degrees centigrade. The water equivalent of the contents of Dewar and that of the cell were measured. The cooling curve of the Dewar with the electrolysis cell was obtained. Calorimetric measurements were performed. The calorimetric measurements were typically conducted over an eight hour period. The input energy was taken to be excess voltage x current x time. The temperature increase, energy increase of the Dewar x the cell was estimated and corrected for heat loss. The result was that the temperature measurements did not indicate as high a cell temperature as expected even in normal conditions. Thus were some factors in the measurements unaccounted for associated with the open system conditions and most probably there was no significant excess heat production.

As we did only a rough experiment, we were hoping for large effects. Had the Pd cathode been better degassed and correctly coated with Pd black, we might have obtained different and better results. At any rate, we decided to halt the experiment since it was not funded. Also, we hoped that the key parameter(s) that have caused the non-reproducibility of each experiment would be identified in labs doing more intensive work. Then we would be in a position to resume work.

KEYWORDS: *plasma discharge, cold fusion*

A NOVEL APPARATUS TO INVESTIGATE THE POSSIBILITY OF PLASMA-ASSISTED COLD FUSION

DAVID N. RUZIC, KENNETH D. SCHATZ, and PHI LONG NGUYEN
University of Illinois, 103 S. Goodwin Ave., Urbana, Illinois 61801

Received May 8, 1989
Accepted for Publication May 11, 1989

Cold fusion of deuterium in a transition metal may have been demonstrated recently. These experiments use electrochemical hydrolysis of heavy water to provide the fuel source and conditions for fusion. An alternate approach with some advantages over electrolysis is described. A dc plasma discharge is made in a deuterium gas with a negative electrode made of palladium. Independent pressure, temperature, and current control are also possible in this method. Detection of reactions is achieved by a charged-particle detector placed close to the back side of the cathode. To date, no fusion events have been seen. However, only a small portion of the available parameter space has been investigated.

INTRODUCTION

Jones et al.[1] at Brigham Young University described a neutron signal attributable to cold fusion in an electrode of an electrochemical hydrolysis experiment involving heavy water and other electrolytes. Fleischmann and Pons[2] at the University of Utah described heat generation in a similar electrochemical hydrolysis setup that used a palladium rod as one of the electrodes. They ascribed the heat generation to nuclear fusion.[2] Both of these experiments are chemistry experiments using heavy water as the source of deuterium and hydrolysis as the method for injecting deuterium into the electrodes. This paper describes an alternate approach using deuterium gas and a deuterium plasma as a method for injection into the electrode. In this apparatus, electrode temperature, electrical current, and gas pressure can be controlled independently. In addition, heavy charged fusion products can be detected (if they exist) through the use of a surface-barrier detector a few millimetres from the back side of the cathode.

Cold fusion is a method of producing nuclear fusion reactions in a metal lattice. Normally, this is prevented by the coulomb repulsion barrier. Some combination of external electric current, saturation of the metal by the fuel, phase change of the deuterium in the metal lattice, and possible other factors may conspire to reduce this barrier enough to allow fusion events to proceed at a detectable, and perhaps useful, rate through quantum mechanical tunneling.

Electrochemical experiments are plagued with fusion detection difficulties. A great quantity of D_2 and O_2 gas is released. The potential chemical energy must be accounted for in determining the energy balance. If some surface recombination occurs, the electrodes can get very hot. Temperature measurements in the electrolyte must be made at many places, and the solution should be stirred to ensure thermal equilibrium. Further, the charged fusion products (3-MeV protons and 1-MeV triton, or 0.8-MeV ^{3}He) cannot be seen because their range in solids and liquids is <0.1 mm. Neutron detection is possible, but is much more difficult than detecting charged particles. Typically, much more care is needed when determining background.

APPARATUS

Figure 1 shows a schematic of the plasma discharge device. It consists of two glass pressure vessels of 18- and 5-cm diameters, one inside the other. The pressure in the two chambers can be controlled independently and can range from 5 mTorr to slightly above atmosphere. The vessels are pumped by a mechanical roughing pump and sealed with O-rings, Dow-Corning silicone vacuum grease, and Vac Seal High-Vac Leak-Seal®. The deuterium gas used in both chambers comes from the same bottle and is 99.9% pure.

A plasma is formed in the inner chamber between two palladium electrodes by a dc current/voltage-limited power supply. A 30-W, 500-Ω resistor is added in series to stabilize the discharge from arcing. The anode is a 1-mm-thick, 5- × 10-mm tab of palladium spot-welded to a tungsten wire. The anode tab is placed with the edge facing the cathode and ~3 cm away. The cathode is a 0.2-mm-thick, 1-cm-diam palladium hemisphere formed from a 1-mm-thick palladium sheet. It is silver-soldered to the edges of a hole in a copper backing plate. A quartz disk with a 0.9-cm hole in its center sits against the copper plate on the inside of the inner chamber to protect the copper plate and silver solder from plasma bombardment. Care was taken to keep the silver solder from wetting the palladium surface. Though no silver covered the electrode surface, an oxide may have formed due to the heating. After construction, the palladium electrode was cleaned and polished by an alumina grinding wheel and a stainless steel brush.

A single-turn copper cooling line is soldered to the copper backing plate. Liquid N_2, cold water, or hot water can

ON THE POSSIBILITY OF DEUTERON DISINTEGRATION IN ELECTROCHEMICALLY COMPRESSED D$^+$ IN A PALLADIUM CATHODE

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *cold fusion, neutron capture, Oppenheimer-Phillips reaction, disintegration, palladium reaction*

MAGDI RAGHEB and GEORGE H. MILEY *University of Illinois*
Department of Nuclear Engineering, 103 South Goodwin Avenue
Urbana, Illinois 61801

Received April 28, 1989
Accepted for Publication May 11, 1989

The possibility of deuteron disintegration due to polarization in the coulomb field of a target nucleus according to an Oppenheimer-Phillips process is discussed within the context of electrochemically compressed D$^+$ in a palladium cathode. This reaction is possible between deuterons and palladium isotopes, as well as between the deuterons themselves. In the last case, the equivalent of the proton branch of the deuterium-deuterium fusion reaction occurs in preference to the neutron branch. The process provides a possible explanation for the observed energy release, tritium production, and neutron suppression in the Fleischmann and Pons experiment. If such a process can be experimentally verified, analogous processes leading to the disintegration of the ^{9}Be nucleus may be achievable.

INTRODUCTION

The possibility of deuteron disintegration in condensed matter is discussed as a model for the processes occurring in the work on cold fusion reported by Fleischmann and Pons[1] and by Jones et al.[2] Other proposed models for these processes include quantum-mechanical tunneling and quasi-electron formation in the deuterated lattices by Jones et al.,[2] classical oscillations of delocalized species in shallow potential wells by Fleischmann and Pons,[1] and cosmic muon catalysis by Moir.[3]

The suggestion by Fleischmann and Pons[1] that the reactions

$$D + D \rightarrow T + H + 4.03\ \text{MeV} \qquad (1)$$

and

$$D + D \rightarrow {}^3\text{He} + n + 3.27\ \text{MeV} \qquad (2)$$

take place to the extent of 1 to 2×10^4 atom/s (consistent with the measurements of the neutron flux), whereas the data on enthalpy generation would require rates for reactions (1) and (2) in the range 10^{11} to 10^{14} atom/s, leads them to conclude that these reactions "... are only a small part of the overall reaction scheme and that other nuclear processes must be involved." They further observe that "... the bulk of the energy release is due to an hitherto unknown nuclear process or processes (presumably again due to deuterons)." This technical note discusses the possibility of deuteron disintegration due to its polarization in the coulomb field of a target nucleus as an explanation of their observations.

DISCUSSION

Early in the study of nuclear reactions, it was observed that (D,p) reactions occur at deuteron energies well below the coulomb barrier of a target nucleus. Moreover, the cross sections are considerably larger than those for the corresponding (D,n) reactions.[4] These two observations are at odds with expectations based on the compound nucleus model, which suggests that there should not be reactions below the coulomb barrier and that neutron emission should predominate over proton emission from the compound nuclei formed. Oppenheimer and Phillips[5] explained this apparent anomaly based on the peculiar properties of the deuteron.

The deuteron is a loosely bound nuclear structure with a binding energy of 2.23 MeV only. This value can be calculated from

$$BE = [Z \cdot M(p) + N \cdot M(n) - M'] \times 931.5$$

or

$$BE = [Z \cdot M(\text{H}) + N \cdot M(n) - M] \times 931.5\ ,$$

where

$M(p)$ = mass of proton
$M(n)$ = mass of neutron
M' = mass of bare nucleus
M = mass of neutral nuclide
$M(\text{H})$ = neutral mass of hydrogen.

Thus, for the deuteron,

$$BE(\text{D}) = \{[M(n) + M(\text{H})] - M(\text{D})\} \times 931.5$$
$$= 2.2246\ \text{MeV}\ ,$$

sck
cen
mol

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TEL ~~(014)~~31.68.71 - 31.18.01
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TLX 31922
~~TLG Centratom Mol~~
~~BTW 406.568.867~~

Mol, September 25, 1989

Concerns : "Cold fusion"

Ref. : F8319092

Dear Sir,

Please find enclosed a report concerning our observations of excess heat production during so-called "cold fusion" experiments and an explanation for the phenomenon we have observed.

We have sent this report to the laboratories where excess heat production has been observed as well, with the request to investigate whether their observations might be explained in a similar way.

We would be grateful if you could send us your comments.

Yours sincerely,

M. SNYKERS

Programme Manager
Fusion Technology

092589..MS

Zetel en Financiële Diensten : Ch. Lemairestraat 1, 1160 Brussel
TEL (02)661.08.11 TFX (02)660.75.63 TLX 22.718 TLG Centratom Brussel

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EXPERIMENTAL EVIDENCE OF ERRONEOUS HEAT PRODUCTION IN COLD FUSION EXPERIMENTS

A. Bruggeman, M. Loos, C. Van der Poorten, R. Craps,
R. Leysen, F. Poortmans, G. Verstappen, M. Snykers

September 1989

BOERETANG 200
B-2400 MOL
Belgium

S.C.K./C.E.N.
Fusion

Mol, September 19, 1989

AB/ML/CVdP/RC/RL/FP/GV/MS/mvds/89/62

EXPERIMENTAL EVIDENCE OF ERRONEOUS HEAT PRODUCTION IN COLD FUSION EXPERIMENTS

A. Bruggeman, M. Loos, C. Van der Poorten, R. Craps, R. Leysen,
F. Poortmans, G. Verstappen, M. Snykers

ABSTRACT

In the course of an electrochemical loading "Fleischmann and Pons type" experiment, an excess heat production has been observed in the cold fusion laboratory of the Nuclear Research Centre in Mol, Belgium. This excess heat was not due to fusion reactions and could not be explained on physico-chemical grounds.

An explanation is given on the basis of a hidden input of electrical energy from the power source, which is not revealed by the standard DC measurements. It consists of a low frequency AC current which is superposed on the applied DC current and may be generated by the occurrence of an oscillation instability in the electrical circuit of the cell.

The actual excess heat production phenomenon could be reproduced during simulation experiments.

1. INTRODUCTION

In the search of cold fusion based on electrochemical loading of palladium with deuterium, several research teams have observed an as yet unexplained excess heat production [Fleischmann and Pons [1], Appleby [2], Huggins [3], , Kainthla [4] and Gozzi (Univ. Rome)].
Attempts to explain this heat production were mainly based on electrochemical or physico-chemical grounds. They were not conclusive [5] [6].
Soon after the Fleischmann and Pons observations became known to the public, similar electrochemical experiments were started at the Nuclear Research Centre S.C.K./C.E.N. The main aim of the programme was to investigate the origin of the excess heat production. Particular attention was paid to the possible influence of various electrochemical parameters.

2. EXPERIMENTAL SET-UP

The experiments have been performed in a specially equipped laboratory, with two cells running in parallel, one with LiOD-D_2O and one with LiOH-H_2O.
The heart of each set-up is a glass electrolysis cell with an outer diameter of 4.5 cm as shown by Fig. 1. As electrolyte solution 0.1 M LiOD in D_2O respectively 0.1 M LiOH in H_2O is used, which is similar to the one used by Fleischmann and Pons. The level in the cell is kept constant by regular addition of D_2O respectively H_2O, except after sampling when 0.1 M LiOD in D_2O respectively 0.1 M LiOH is added. For both cells, the quantity of electrolyte solution is about 50 ml.

The electrolysis cells are equipped with 3 electrodes :

- A central palladium rod (Pd), or working electrode, which may be loaded cathodically with D (H). The Pd electrodes used are cylinder-shaped rods with a diameter of 0.4 cm and a length of 5.0 cm. At the top they are equipped with a 0.1 cm diameter Pd wire. This wire and also all parts emerging from the solution are electrically insulated. The used enamel constitutes also a diffusion barrier for deuterium (hydrogen).

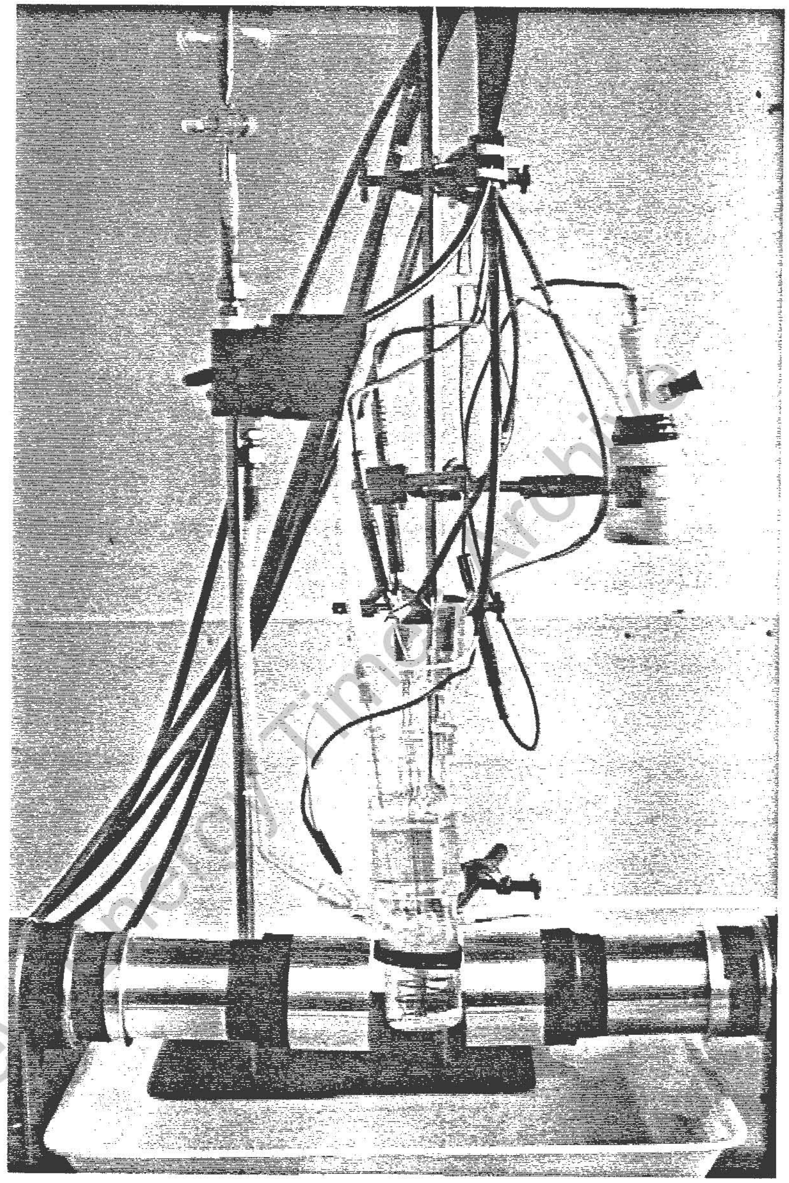

Fig. 1 : Assembly for D_2O electrolysis. In the middle : glass cell with working electrode (Pd), electrolyte bridge to the reference electrode (Hg/HgO) and counter electrode (Pt). Left and right of the cell : liquid scintillation detectors for neutron detection.

To keep the formed D_2 (H_2) more or less separated from the formed O_2, a reversed glass funnel has been placed around the Pd wire and around the upper part of the Pd rod; this funnel is immersed in the liquid and allows the vertically bubbling D_2 (H_2) to escape. The Pd has been supplied by Johnson Matthey and has not been pretreated for the experiments realized up to now.

- A platinum (Pt) electrode or counter-electrode, i.e. an electrode for closing the electrical circuit. This electrode consists of a Pt wire with a diameter of 0.1 cm and a length of about 25 cm; it is wound in a spiral around the Pd electrode at a distance of about 1 cm.

- A Hg/HgO reference electrode, i.e. an electrode for controlling and/or monitoring the electrochemical process. The potential of the Hg/HgO reference electrode at 25°C in 0.1 M LiOH is + 0.166 V with respect to the standard hydrogen electrode. This reference electrode is connected to the electrolyte solution by means of a bridge of LiOD respectively LiOH solution.

A well-determined potential E or current I is obtained by using Amel potentiostats/galvanostats (model 550), and, if necessary, completed by a function generator (Amel, model 567).

Continuous and automatic recording of data is realized by means of a personal computer, a multichannel scanner (SCK type 702), a Schlumberger Solartron voltmeter (model 7060) and the necessary hard- and software.
It concerns the following data.

- The potential difference, E_{ref}, between reference and working electrode, with $E_{ref} = - E_W$, in which E_W is the potential difference of the working electrode compared with the reference electrode (Hg/HgO). The (cathode) potential of the working electrode compared with the standard hydrogen electrode is given by :

$$E_K = - E_{ref} + 0.166 \text{ V} = E_W + 0.166 \text{ V} \qquad (3.1)$$

- The total cell tension, U_{cell}, i.e. the terminal voltage between counter- and working electrode.

- The cell current I.
- The temperatures inside (T_{in}) and outside (T_{out}) the electrochemical cell, measured with Pt 100 thermistors not corrected for mutual deviations.

All values are measured about every 15 s. An average value is recorded per adjustable time interval (usually 6 to 8 minutes).

The neutron detection system consists of two independently working proton-recoil liquid scintillators, type NE213 (Ø = 5 cm, h = 5 cm). The pulse-height spectra (2 x 2 K) are stored in a multichannel analyzer with multiplexer. The absolute efficiency of these detectors had been determined previously for various neutron energies between 0.5 MeV and 16 MeV at the Van de Graaff accelerator of CBNM. Pulsed mono-energetic neutron beams were produced with the reactions $T(p,n)^3He$, $D(d,n)^3He$ and $T(d,n)^4He$ and a calibrated proton-recoil telescope was used as reference detector.

The detectors are installed at a few mm from the D_2O cell so that the total efficiency for 2.5 MeV neutrons is 5 % per detector with a bias level at 1.2 MeV. Puls-shape discriminator is used to reduce the background from gamma radiation. The total background per detector is $4.3\ 10^{-3}$ counts per second with a bias of 1.2 MeV.

An unshielded 3" x 3" NaI (Tl) detector, coupled to a multichannel analyser with a range of 0.1 to 10 MeV (Canberra series 35 plus), has been installed in the immediate vicinity of the D_2O cell for the measurement of the gamma-rays which might be created directly or by interaction (a.o. in the detector itself) of produced neutrons.

The tritium activity of the used solutions 0.1 M LiOD in D_2O and 0.1 M LiOH in H_2O before a test and the tritium activity in the cells after a test period, are measured by liquid scintillation counting with a precalibrated Packard Tri-Carb device (model 4430) equipped with DPM and Spectraview options. It is supposed that possibly produced tritium finally (partially) arrives in the solution. This hypothesis seems to be justified because of the selective enrichment of lighter hydrogen isotopes in the palladium and of heavier ones in the electrolyte solution [7, 8]. Further details concerning the experimental set-up can be found in ref. [9].

3. EXCESS HEAT PRODUCTION EXPERIMENT

In accordance with the ideas of Fleischmann and Pons [1], the main part of the experiments consisted in a continuous electrochemical loading of palladium electrodes with deuterium respectively hydrogen. Loading was carried out at controlled cathode potential, i.e. at a constant negative potential E_w of the working electrode compared with the Hg/HgO reference electrode. A general survey of experiments performed is given in ref. [9].

The present report only deals with the experiments when excess heat production was observed.

On 16.06.1989, after two months of experimentation, a sudden temperature rise occurred in both cells, as shown in Fig. 2. The two cells were than in operation for 46 h in conditions given in Table 1. The working conditions for both cells had been stable for the past 46 hours.

	I	U_{cell}	$T_{in} - T_{out}$
D_2O cell	0.3 to 0.5 A	4.0 to 4.7 V	3 to 5°C
H_2O cell	0.2 to 0.25 A	3.0 to 3.5 V	1.0 to 1.5°C

E_w = - 1.6 V compared with Hg/HgO
Environmental temperature : 28-30°C

TABLE 1
Working conditions of the cells

The heating of the cells corresponded with a power of more than 20 W. Yet, the measured values of I, U_{cell} and E_{ref} (= - E_w) dropped to lower values than before [Fig. 3]. U_{cell} and E_w were checked at the cell with a portable multimeter and the measured values corresponded with the recorded (low) values. On the basis of the measured values the dissipated heat had to be less than 0.4 W for both the D_2O and H_2O cell.

After 1 h, when decoupling the function generator, the H_2O cell suddenly normalized. This had no effect on the D_2O cell. Replacement of the potentiostat had also no result. The D_2O system was no longer controllable and the cell had to be cooled by means of a cold air blower. For the D_2O cell, this abnormal situation lasted for about 2 h, so that the dissipation may be estimated at 100 to 200 kJ.

The potentiostats themselves also dissipated more heat than normally. The PdD_n (PdH_n) cathodes behaved rather normally but around the Pt counter electrode of the D_2O cell strings were formed.

After about 2 h, normalization of the D_2O cell suddenly occurred when taking a 5 ml sample from the hot LiOD in D_2O solution in view of the tritium content measurements.

The tritium activity in the D_2O cell was increased by about 65% to 2.6 Bq/g as compared with the initial tritium activity. Because of the known tritium enrichment in the electrolyte solution during electrolysis of D_2O, the measured tritium concentration can not be considered to be abnormally high.

In the course of this process of abnormal heat production, the neutron measurement equipment did not show any evidence of a neutron production, however a previously non observed defect occurred in the gamma measurement circuit. An ordered peak pattern appeared in the channels corresponding normally with energies from 4 to 8 MeV. Above 8 MeV still smaller peaks appeared. This was due to a temporary defect of the measurement equipment.

On the basis of those observations it was clear that the excess heat was not produced by nuclear fusion reactions.
There was also considerable doubt that it was due to a chemical reaction since an energy release of 100 to 200 kJ can be produced by the oxidation of 0.5 ml deuterium, or 10 times the maximum capacity of deuterium to be expected in the Pd D_n cathode.

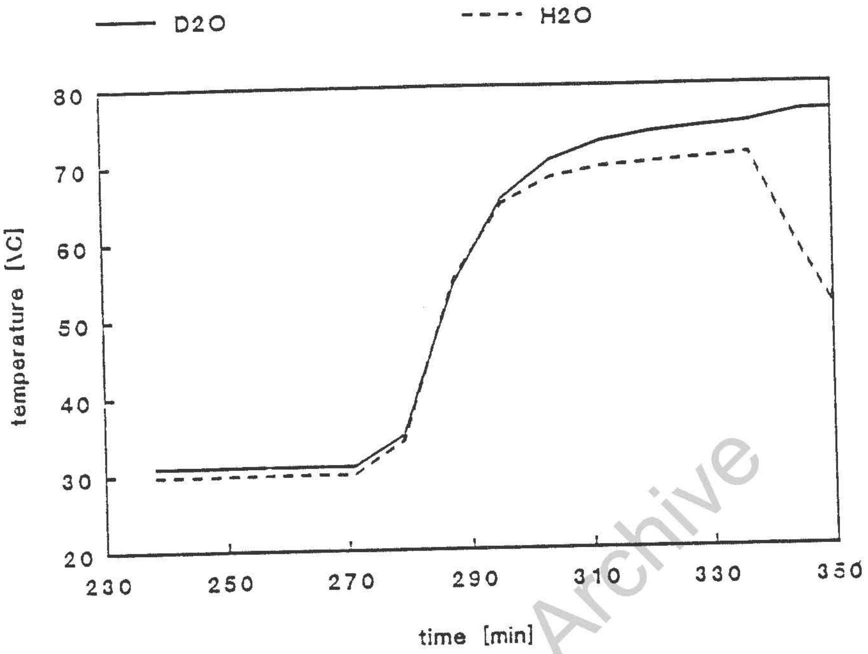

Fig. 2 : Excess heat production observed in D_2O and H_2O cells

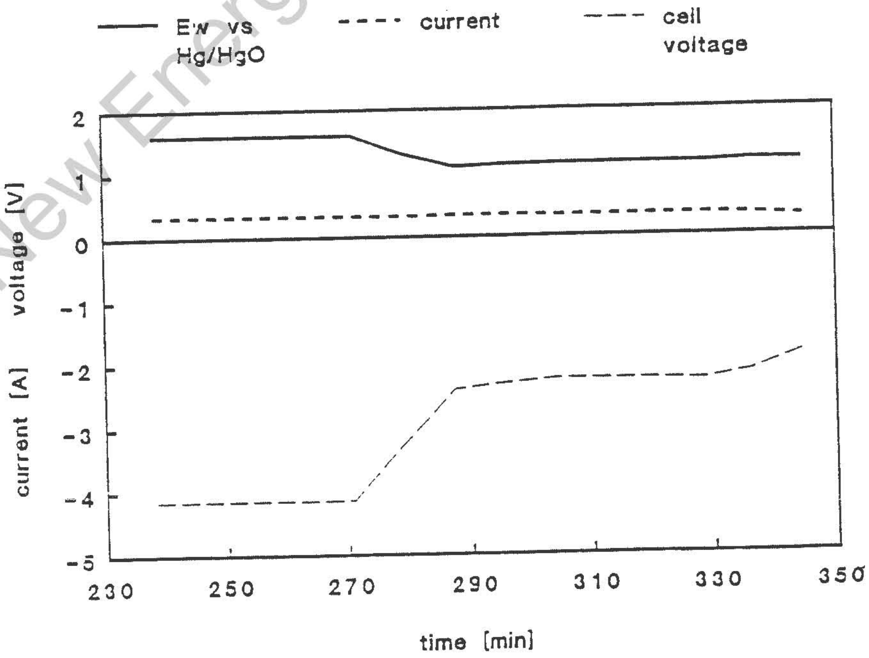

Fig. 3 : DC measurements while excess heat production was observed with the D_2 cell (results obtained with H_2O cell are similar)

For those reasons, the search was continued mainly in the direction of a hidden energy input e.g. an alternating current.

4. EXCESS HEAT PRODUCTION SIMULATION

Ostensible excess heat production may occur if an alternating current is superposed on the direct current which feeds the cell.
The probability that this will be induced by the AC from the mains is very low since the DC power supply equipments are very well protected against this. An examination of the potentiostats and the pulse generators did not reveal any defects.
An other possibility is that the electrical circuit approaches an oscillation instability.
An experiment was performed where an AC current with varying frequency was superimposed on the DC current. For a frequency of 50 Hz the obtained measurements were quite well in agreement with those observed in the June experiment. This component is not measured in standard electrochemical experiments since the DC measurement equipment integrates over 20 ms.
A computer simulation of the electrical circuit, shown in Fig. 4, composed of the power source, the electrochemical cell and the feedback through the reference electrode (Hg-HgO) was performed in order to detect those components which may contribute to oscillation. This study showed that for the configuration used in the experiment an oscillation could be induced by a cascade of two integrations, one related to the working electrode and one to the feedback circuit.
Based on those results, experiments have been performed on simulated and real cells. In the real cell the palladium was exchanged by platinum.
The following parameters were varied :

- the capacitance (Cref) at the reference input of the potentiostat;
- the resistance of the electrolytic bridge (Rref);
- the resistance of the connection (lead + contact)(Rcon) between the working electrode and the "working" input of the potentiostat.

The results obtained with the real cell are shown in table 2.
With a well functioning cell (good connections and low resistance of the electrolytic bridge) oscillation occurs with a capacity Cref of at least 0.2 μF near 80 Hz.
This frequency lowers to near 50 Hz for a Cref of 0.47 μF.

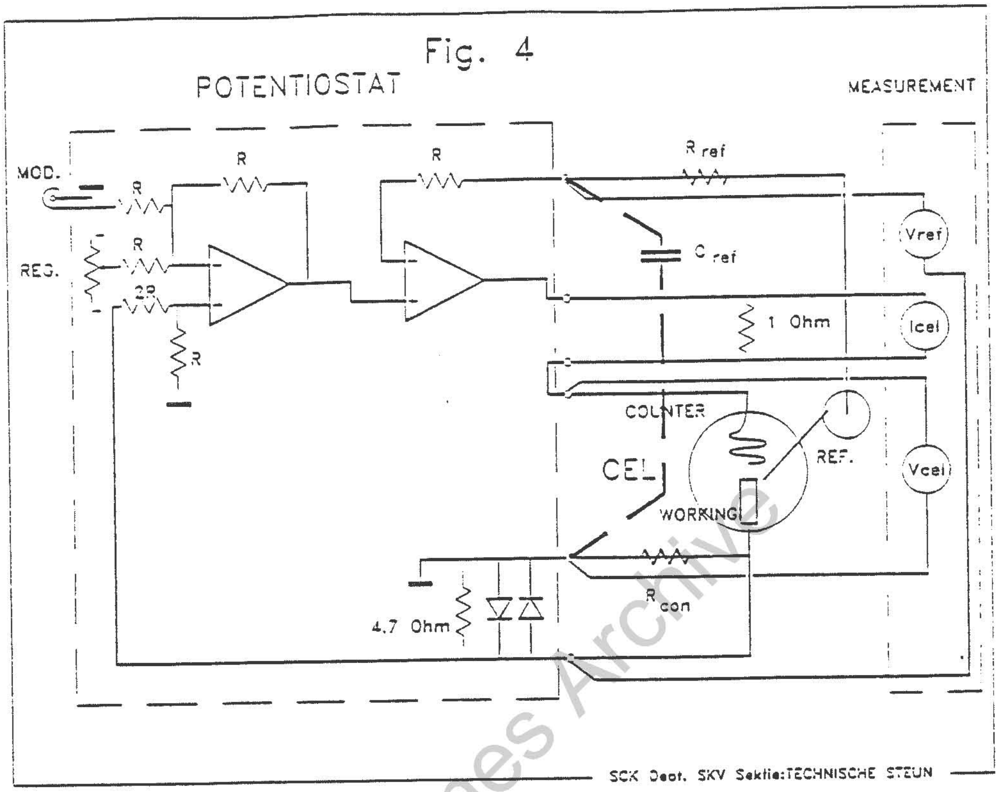

Fig. 4 : Electrical circuit of the connection of the potentiostat to the working cell (CEL) and the reference electrode (ref.). The extra resistances Rref and Rcon and the capacitance Cref are also shown.

	Single cell				Configuration with 2 cells in parallel
Rref	normal	normal	high	high	high
Rcon (cable to working cell)	normal	increased	normal	increased	increased
Cref (for oscillation)(μF)	0.2	0.1	0.07	0.02	0.01

TABLE 2

Experimental results giving rise to oscillations

In case a bad connection (resistance of a few ohm) occurs between the working electrode and the potentiostat, the required capacitance for oscillation lowers to about 0.1 μF.
If the resistance in the electrolytic bridge increases to a high value (e.g. 2 MOhm) and the rest of the cell is in good working condition, the cell continues to function properly. In this case a capacitance Cref of 0.07 μF is sufficient to induce oscillation (at 32 Hz).
If on top of this also a bad connection occurs as mentioned in a previous case, the required capacitance lowers to 0.02 μF for full power oscillation at 15 Hz and to 0.003 μF for low power oscillation at 58 Hz.

In the actual experimental set-up for the cold fusion experiments the modulation inputs of the potentiostats of the two cells were coupled to the pulse generator. The screening of the connection cable is connected to the sensitive side of the input. This particularity of the modulation input of the potentiostats yields an electrical coupling between the two cell systems. It facilitates pick-up of external signals. In this case only a high resistance in the electrolyte bridge is sufficient to detect a considerable 50 Hz signal on top of the DC potential.
If in this case also a bad connection of the working electrode and a high resistance in the electrolytic bridge occurs, the required capacitance for full power oscillation is lowered to 0.01 μF at 50 Hz.

5. DISCUSSION

Based on the electronic analysis of the systems, experimental evidence is given that a 50 Hz component may become superposed on the DC potential if some "faulty conditions" (perhaps supported by changing electrode capacitances) occur at the same time in the electrical circuit of the cell. This AC component will not be detected by the DC measuring equipment.
The required capacitance, Cref, may be build up partially by the electrical connection lead between the power supply and the cell and a capacitance at the reference electrode.
The high resistance at the reference electrode, Rref, can be caused by insufficient wetting of the electrolytic bridge or the presence of a gas

bubble. The cell continues to function properly, even with an increased resistance in the feedback to the reference electrode.
In case the near instability conditions have been established, the oscillation may be triggered by an 50 Hz perturbation coming from an external source.
The actual energy input due to the 50 Hz AC component depends on the values of Cref, Rref and Rcon.

6. CONCLUSION

Excess energy has been observed during a Fleischmann and Pons type cold fusion experiment.
This phenomenon may be explained on the basis of a hidden input of electrical energy, which is not revealed by the standard DC measurements done in this type of electrochemical experiments.
The hidden electrical energy consists of a low frequency AC power which is superimposed on the applied DC power. It may be generated by the occurrence of an oscillation instability in the electrical circuitry of the cell in case certain faulty conditions build up.
The actual excess heat production phenomenon could be reproduced in simulation experiments.

ACKNOWLEDGEMENTS

The authors are indebted to the numerous S.C.K./C.E.N. personnel members for their advice and help, more particularly K. Gooris (glass cells), H. Elslander and R. Cornelissen (calorimetry), F. Ven (gamma spectrometry), P. D'Hooghe (neutron measurements), R. Menil (BF_3 counter), P. Diels (XRD analysis), S. Nonneman (neutron radiography), D. Vanpee (literature), M. Van der Schueren (typing) and G. Michiels (translation). For valuable discussions and suggestions they are indebted to a.o. G. Spaepen, H. Tas, A. Rahier, W. Wegener, P. Geuzens, A. Blanchart and J. Cornelis. This research is being supported by the Commission of the European Community, DG XII, Fusion.

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Department of Chemistry
Graduate Chemistry 104
State University of New York at Stony Brook
Stony Brook, New York 11794-3400

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Tritium

Report Prepared for the ERAB Panel on Cold Fusion

Jacob Bigeleisen
Department of Chemistry
State University of New York, Stony Brook
Stony Brook, New York 11794 - 3400

20 September 1989

Tritium

One branch of the D - D reaction produces 1 MEV tritons and 3 MEV protons. In conventional fusion reactions the branch to produce tritium is equal to the neutron production branch. All experiments to date , in the range above 1 KEV, show that this ratio is insensitive to the deuteron energy. Theory predicts that the ratio will not change significantly down to deuteron energies in the volt to millivolt range. In a few experiments there have been direct searches for emitted high energy tritons[1] or protons[2,3] from electrolytic cells with Pd cathodes. These experiments give fusion rates 10^{-1},10^{-2} and 1 times, respectively, lower than the neutron production rate reported by Jones[4], 1×10^{-23} fusions/sec./D - D pair. A number of searches have been made for the tritium accumulated during the electrolysis of D_2O with palladium cathodes. In such experiments it is important to determine the initial tritium content of the D_2O and take cognizance of the fact that the electrolysis of the D_2O will enrich the natural occurring tritium in the heavy water.

The detection of tritium by measurement of its beta decay is inherently a less sensitive probe of the D - D reaction than the direct measurement of neutron production or charged particle production. 10^7 tritium atoms give 1 β^- particle per minute.

Tritium is produced in the atmosphere by cosmic ray bombardment. Most of the cosmic ray produced tritium ends up in the oceans and in rivers. The "natural" abundance of tritium varies widely and was greatly increased by atmospheric testing of thermonuclear weapons in the '50s and in the early '60s. The order of magnitude of tritium in ordinary water is $T/H = 10^{-18}$ (1 TU). Sources vary from 1 to 200 TU. The production of heavy water from ordinary water is even more efficient in the enrichment of tritium than deuterium from the feed material. Most of the heavy water currently available is produced by the H_2S - H_2O dual temperature exchange process (GS process). The tritium content of fresh heavy water produced by the GS process is 68 dpm/ml. D_2O/TU feed. Processes which are more efficient than the GS process in heavy isotope enrichment will have a minimum tritium specific activity of 50 dpm/ml. D_2O/TU feed. Heavy water currently being sold on the open market has a specific activity in the range 120 - 180 dpm/ml. D_2O. There are sources with a specific activity as high as 10^4 dpm/ml. D_2O.

Most of the work done to date on the search for tritium produced in the electrolysis of D_2O in cells with palladium cathodes has been done in open cells. The measurements are frequently limited to assays of the specific activities of the starting D_2O and the electrolyte after electrolysis. In general, there have been periodic additions of D_2O to replace the D_2O decomposed to form palladium hydride and $D_2(g)$. To determine how much tritium, if any, has been produced requires a complete inventory of the tritium at the beginning and end of the experiment. From the data on the current and duration of the electrolysis it is possible to estimate the amount of D_2O which has been electrolyzed. Electrolysis will enrich the tritium in the D_2O of an electrolytic cell. The amount of enrichment is primarily a function of the amount of water electrolyzed for a given type of cathode. It can reach a factor of 5 when 95% of the initial charge of water is electrolyzed. Thus a careful analysis of an electrolytic experiment must be carried out if one is to interpret tritium specific activities after electrolysis below 1000 dpm/ml. D_2O as anything other than electrolytic enrichment.[5]

Null Experiments

Most of the work reported to date on the search for excess tritium produced in electrolytic cells can be accounted for by the electrolytic enrichment process. This includes the original report by Fleischmann and Pons[6], and experiments at ANL,[7,8] BNL,[9,10,11] Cal Tech,[12] CRNL,[13] INEL,[14] LLNL,[15] NRL,[16] ORNL,[17,18] Sandia,[19] SRL,[20] Texas A & M,[21] and Utah.[22]

Tritium Bursts

A small number of experimenters report occasional irreproducible amounts of excess tritium in their D_2O samples taken from their electrolytic cells after days of operation. This includes observations by Storms[23] at Los Alamos and Fuller[17] and Scott[18] at ORNL. The ORNL experiments show single cases of an excess of tritium which is of short duration, after which the cell returns to background level. Storms reports excess tritium, 100 times background, in two cells out of fifty.

Closed Cells - Correlation with Excess Heat

Four different groups[10,13,18,21] have now looked for tritium production in closed electrolytic cells. These experiments detect all the tritium from the electrolytic process with the exception of that which may be contained in the Pd cathode. In general, the deuterium inventory in the cathode is negligible compared with the D_2O. Only that tritium formed within the cathode and which remains there because of slow diffusion is unaccounted for. There is no electrolytic enrichment of the tritium in the make up D_2O. In these experiments the total amount of excess tritium found in the total D_2O is less than 10^4T atoms/sec. If this tritium is produced by the D - D reaction, then the maximum amount of excess power (cold fusion power) is 10^{-5} milliwatts. In one experiment[22] in an open cell there was a heat burst of 35 watts for 90 minutes (187,000 joules). The tritium was measured after the burst and no excess above the electrolytic enrichment was found. Clearly the heat burst does not comes from the D - D reaction.

High Levels of Tritium

Two groups[24,25] find tritium at levels of 10^{12} to 10^{14} T atoms/ml. D_2O after periods of electrolysis of the order of hours. This amount of tritium cannot be produced by electrochemical enrichment with the D_2O volume reductions reported. The results of the Bockris[24] group at Texas A & M for cells in which excess tritium was found are given in Table 1 of their paper, reproduced here. Excess tritium is not found in all of their cells. A lisitng of cells in which no excess tritium was found is given in their Table 4. The Bockris cells are 0.1 M in LiOD and have nickel anodes. They precipitate nickel oxide during the electrolysis; some nickel is also electroplated out on the palladium cathode. In one experiment, A8, the specific activity of the D_2 gas produced by the electrolysis was measured. It is 100 times that of the electrolyte. $D_2(g)$ containing tracer amounts of tritium and in equilibrium with $D_2O(l)$ has a specific activity of 0.6 that of the liquid D_2O. If the tritium is formed during electrolysis, then this result suggests that it is formed in the chemical species DT and that the tritium in the liquid D_2O is the result of hot atom processes or slow isotopic exchange of the DT(g) with $D_2O(l)$[26]. Wolf[27] et. al. at Texas A & M have looked for neutron production in Bockris type cells. An upper limit to their neutron production rate is 1 neutron/second, which is 10^{-10} times that of the tritium production rates reported by Packham et. al.[24] This large discrepancy from the usual equal production rates for neutrons and tritons leads one to question whether the excess tritium found in the electrochemical cells results from the D - D nuclear reaction. Another source of concern is the fact that 1 MEV tritons will react with deuterium to produce 14 MEV neutrons. With the claimed triton production rate, 10^{10} tritons/sec., one should find (number to be inserted by RLG) neutrons/sec from the D - T reaction in these cells.[28]

The most extensive and systematic search for tritium in the electrolysis of D_2O with Pd cathodes has been carried out by Martin[21] at Texas A & M. He has used both open and closed cells. His cathodes come from either Johnson & Mathey, the major supplier, or Hoover and Strong, who supplied the cathodes to the Bockris[24] group. He has operated cells with Pt, Ni wire and Ni gauze (obtained from Bockris) anodes. In none of his cells does he find any excess tritium beyond that expected from electrolytic enrichment. Nor does he find any neutrons. Two of his cells produced excess heat but no tritium. In short, he has been unable to reproduce the results of the Bockris group.

The BARC[25] group have found amounts of tritium comparable to the Bockris group in the D_2O electrolyte from cells in which electrolysis was carried out for a few days with currents varying between 1 to 100 amperes. The BARC group also looked for neutrons using BF_3 counters embedded in paraffin. They report neutron bursts of up to 100 neutrons in a 100 μ second time interval. Their integrated neutron yield is 10^{-8} times that of their integrated tritium yield.

The BARC group have also looked for neutrons in the thermal cycling of Ti pressurized with D_2 gas. They report neutron emissions for periods of 30 minutes to 7 hours after cycling between room temperature and 77 °K. Autoradiograhs of the Ti targets from these experiments show intense spots which the authors attribute to beta emission from the decay of the tritium embedded in the Ti lattice.

Conclusions

The experiments carried out to date, which include the large number of null experiments, the few experiments which are irreproducible and in which excess tritium is found, and the large ratio of tritium to neutron production in these experiments, do not provide convincing evidence for the production of tritium by cold fusion phenomena. Additional experiments are desirable to clarify the origin of the excess tritium which is occasionally observed.

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25. P.K. Inyengar, "Cold Fusion Results in the Bombay Atomic Research Center (BARC) Experiments". Paper presented at the Fifth International Conference of Emerging Nuclear Energy Systems (ICENES V). Karlsruhe, 3-6 July 1989.

26. J. Bigeleisen, letter of 26 Auguat 1989 to J.O'M. Bockris.

27. K.L. Wolf, N. Packham, J. Schoemaker, F. Cheng and D. Lawson. Proc. of the Santa Fe Cold Fusion Workshop, in press.

28. R.L. Garwin, private communication.

TABLE 1
CELL IDENTIFICATION, ELECTRODE TREATMENT, SOLUTION TYPE AND TRITIUM ACTIVITY OF ELECTROLYTE SAMPLES PERFORMED ON 1219 LSC

CELL	ELECTRODE PRETREATMENT[a]	SOLUTION	CORRECTED ^3H ACTIVITY (dpmml^{-1})
A1	No treatment	0.1M LiOD	3.8 x 10^4
A2	No treatment	0.1M LiOD + 0.1mM NaCN	
	After 16 days at 50 mAcm^{-2} then for 8 hours at 500 mAcm^{-2} (5/1/89)		168
	50 mAcm^{-2} for 4 days (5/5/89)		134
	50 mAcm^{-2} for 3 hours, 110 mAcm^{-2} for 2 hours, 200 mAcm^{-2} for 20 minutes (5/6/89)		1.1 x 10^4
	50 mAcm^{-2} (5/7/89)		1.4 x 10^4
	(5/7/89 - 5/13/89)		1.1 x 10^4
	(5/13/89 - 6/6/89)		7.5 x 10^3
A3	Anneal	0.1M LiOD	4.9 x 10^6
A4	Anneal	0.1M LiOD + 0.1mM NaCN	1.2 x 10^5
A5	Acid Etch	0.1M LiOD	3.7 x 10^6
A6	Acid Etch	0.1M LiOD + 0.1mM NaCN	3.3 x 10^4
A7	Electrochemical	0.1M LiOD	
	Before high current density		102
	After 2 hours at 500 mAcm^{-2}		5223
	After 6 hours at 500 mAcm^{-2}		5.0 x 10^5
	After 12 hours at 500 mAcm^{-2}		7.6 x 10^5
A8	Electrochemical	0.1M LiOD + 0.1mM NaCN	
	After 16 days charging and 8 hours high current density (5/1/89)		192
	Electrolyte levels after 6 weeks at 50 mAcm^{-2}		5.0 x 10^5
	Recombined gas levels after 2 weeks of external recombination at 50 mAcm^{-2}		5.0 x 10^7
B3 (3mm)	Anneal	0.1M LiOD	6.3 x 10^4
B5 (3mm)	Acid Etch	0.1M LiOD	48
CELL 1 (6mm)	No treatment	0.1M LiOD	117

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[a] Key for electrode surface pre-treatment: Anneal - annealing at 800 °C, 10^{-6} torr, 8 hours; Acid etch in 5M HCl, 15 minutes; Electrochemical oxide removal, 2 hours

TABLE 4
DETAILS OF CELLS THAT PRODUCED NO TRITIUM WITH 1410 LSC (CORRECTED ACTIVITY)

EXPERIMENT	$dpmml^{-1}$
3mm x 3cm Ti Cathode in 0.1M LiOD with internal gas recombination	275
3mm x 3cm Pd Cathode in 0.1M LiOD with internal gas recombination	235
3mm x 3cm Ti Cathode in 0.1M LiOD with internal gas recombination	285
0.5mm x 1cm Pd Cathode in 0.1M LiOD with internal gas recombination	55
4mm x 2mm Pd disc Cathode in 0.1M LiOD with internal gas recombination	365
0.5mm x 1cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured)	315
1mm x 4cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured 7/18/89)	75
1mm x 4cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured 7/21/89)	33
1mm x 4cm Pd Cathode in 0.1M LiOH (H_2O) No gas recombination	0
1mm x 4cm Pd Cathode in 0.1M LiOH (H_2O) No gas recombination	18

StonyBrook

Department of Chemistry
State University of New York at Stony Brook
Stony Brook, New York 11794-3400
(516)-632-7905
BITNET: JBIGELEI@SBCCMAIL
FAX: 516-632-7960

20 September 1989

Professor Kevin Wolf,
Cyclotron Institute,
Texas A & M University,
College Station, Texas 77843-3366

Dear Kevin,

I am preparing the section on "TRITIUM" for the final ERAB Panel report on cold fusion. I have reports from Bockris and Martin at Texas A & M on their tritium work. I understand that you have also made some tritium measurements on your own. If so, would you kindly complete the attached questionnaire which has been prepared by the panel and circulated by the chairman, Prof. John R. Huizenga.

For those few cases where people have observed tritium I am trying to estimate the secondary neutron production from the well known D + T reaction. For this purpose could ypou furnish me with the following information concerning your neutron measurements:

1. volume of D_2O in cell
2. neutron counter efficiency
3. counter geometry factor
4. neutron counting rate (including those cells that gave tritium and those that did not.

I would appreciate a prompt response. Thank you.

Jacob Bigeleisen

Jacob Bigeleisen

xc: W. Woodard

Date: 20 September 1989, 10:42:09 EDT
From: (R.L.Garwin (914) 945-2555) RLG2 at YKTVMV
IBM Fellow and Science Advisor to the Director of Research
P.O. Box 218
Yorktown Hts, NY 10598
To: (Jacob Bigeleisen (516) 632-7905) JBIGELEI at SBCCMAIL
HOFFMAN at LBL.GOV
KOONIN at CALTECH
SCHIFFER at ANLPHY
SMITH at ANLPHY
Subject: Thick-target yield of neutron from T on metal deuterides (correction)
Reply-To: RLG2 at WATSON

Please replace yesterday's similar communication with this one:
For determining the 14-MeV neutron output from a 1-MeV recoil triton, we can refer to J.E. Bounden, et al, NUCLEAR INSTRUMENTS AND METOHDS, Vol. 33, 283-288 (1965). They built an tube accelerating 50:50 D-T against an Erbium target ErD1T1 and found thick-target yields stable in time at more than 10**8 neutrons per microcoulomb, for beam energies above about 200 keV.

If one does not require stability against T replacing D in the target (the reason Jim Coon devised the mixed D-T beam), one accelerates T against a D-loaded target and picks up a factor 2 in neutrons per microcoulomb; since the mixed-beam vs. mixed target reacts each incident T only against target D, and each incident D only against target T.

Thus the yield is 2x10**8 / 6x10**12 or 3.3x10**-5 neutrons per triton. This is for Er with Z=68, loaded with two hydrogens each. Titanium with Z=22 and two hydrogens will be at least twice as productive, and even TiD will give as many neutrons as ErD2. Pd with Z=46 (as PdD) will still give at least 2x10**-5 neutrons per incident triton.

Recoil tritons will provide at least as many neutrons as will a 200 keV beam, because every triton will have the 200 keV trajectory at the end of its range, in addition to the high-energy tail of the resonance.

Dick Garwin

22 SEP 89
R.L. GARWIN

Lawrence Berkeley Laboratory
1 Cyclotron Road Berkeley, California 94720

Building 70A, Room 3307

TEL. (415) 486-5661, FTS 451-5661
FAX: (415) 486-4515
BITNET: NSD@LBL
TELEX: 910-366-2037 Answerback: LBL BERK

FAX TRANSMITTAL

✓

TO: Dr. Richard Garwin 2556
IBM Fellow & Science Advisor to the Director of Research
IBM CORPORATION
P. O. Box 218
YORKTOWN HEIGHTS, NY 10598

FAX NUMBER: 914-945-2141

FROM: Professor Darleane C. Hoffman 70A/3307 Lawrence Berkeley Lab Berkeley, CA 94720

DATE: September 20, 1989

TOTAL NUMBER OF PAGES INCLUDING COVER PAGE: 3

092089.DCH

Protons

Working Draft prepared for Cold Fusion Panel Working Group on Fusion Products, Darleane C. Hoffman, UCBerkeley & Lawrence Berkeley Laboratory. e-mail address: Hoffman@lbl.gov. FAX #: 415-486-4515.

A few experiments[1-4] to measure the 3 MeV protons and/or the 1 MeV tritons produced in the reaction, D(d,p)T, have been reported. A variety of different methods has been used, but the lowest limit on charged-particle production appears to be that set by Price et al.[1] using plastic track detectors. Their setup was designed so that the light water control cell matched the heavy water cell as closely as possible. Cathodes of 25-micrometer-thick Pd sheet with a 100 nm Au diffusion barrier evaporated on the side which faced the plastic (CR-39) detector, and anodes of 2 micrometer Pd evaporated on 100 nm Au on microscope slides were used. The light water control cell contained 1 M LiOH and H_2O and the other cell contained 1 M LiOD and D_2O. Electrolysis was performed for 13 days, and the cathode stoichiometry was determined to be $Pd(H,D)_{0.8}$. Both cells showed track production rates which agreed and were consistent with the alpha-particle emission rate for native Pd foils due to trace ppm) impurities of the natural U-238 and Th-232 decay chains; however, no tracks due to protons with energies between 0.2 and 3 MeV or tritons with energies between 0.2 and 1 MeV were found. From these data Price et al.[1] set limits on the fusion rate of less than 0.002 per cm^3 per second. This value results in an upper limit of 8.3×10^{-26} fusions per dd pair per second. This is about an order of magnitude lower than the limits obtained using Si surface barrier (SSB) techniques.

A limit on the fusion rate of 0.0281 per cm^3 per second or 1.2×10^{-24} fusions per dd pair per second was obtained by Zeigler et al.[2] using a SSB technique. Porter et al.[3] used a SSB detector to view the back of a 76 micron thick Pd foil cathode in a heavy water electrolysis cell. They obtained a limit of less than 6×10^{-25} protons per dd pair per sec at the 2 sigma level; chemical analysis of their electrolytes showed no evidence for anomalous increases in tritium concentrations. Sundqvist et al.[4] also used a SSB technique to detect protons. The detector was placed close to Pd foil cathodes which were thin enough to allow all the protons produced to escape from the foil. All of their runs gave a result of 0 within the statistical errors, resulting in a fusion rate of $(-2.1+/-2.2) \times 10^{-24}$, if a bulk process is assumed.

Recently, Rehm et al.[4], have reported using a proportional counter to search for charged particles from electrolytic cells with Pd and Pt electrodes in 0.1 M LiOD in D_2O. They obtained an upper limit of 4 x 10-23 fusions per dd pair per second, not as low as the limits using the other methods.

CONCLUSIONS

A variety of experimental techniques has been used in searches for charged particles; all of them set very low limits on fusion occuring via the D(d,p)T channel. Most of these results set limits on fusion via this channel that are considerably less than Jones et al.'s[5] value of (1.00+/-0.82)x10-23 fusions per dd pair per second for the D(d,n)^{3}He channel obtained from neutron measurements. (Sundqvist et al. calculated the uncertainty for this value.)

The upper limit of Price et al. of 8 x 10-26 fusions per dd pair per second is much below the average low rate inferred from the neutron measurements of Jones et al.[5] and even those of Menlove et al.[6] The extremely low limits which the searches for charged particles place on the production of charged particles (either protons or tritons) is clearly inconsistent with the reported production of tritium via the cold fusion reaction.

(A Table of results could be appended here.) Also, I have just talked with Buford Price and he will have some new results to me tomorrow on work they did on cleavage cracks in LiD which set limits for fusion which are a factor of 30 lower than those reported some time ago by a Russian group. I will circulate the info as soon as I can.

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master 09/27/89

Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
(914) 945-2555

September 19, 1989

Mr. John P. Schiffer
Physics Letters B
Editor of Experimental Intermediate-
Energy and Heavy-Ion Nuclear Physics
Physics Division - 203
Argonne National Laboratory
Argonne, IL 60439-4843

Dear John,

Draft for John Schiffer. I will put this into final form for our group after I return 10/07/89 from Italy and the Soviet Union.

Fusion Products: Neutrons.
(R.L. Garwin Draft of 09/19/89)

Neutrons are both expected and observed from observations of nuclear fusion of d+d. In the fusion of beams of d on heavy ice targets, or on metal hydrides, almost one 2.45 MeV neutron is produced (with an accompanying He-3), for every triton (with an accompanying proton). This near-equality of neutron and proton branches of the d+d reaction is a reflection of the basic symmetry of nuclear forces between proton and neutron, disturbed only slightly at the MeV energies of the emerging particles, by the Coulomb interaction which is not symmetrical between proton and neutron.

Even at the low reaction energies typical of muon-catalyzed fusion (something like 3 keV above zero relative kinetic energy), the branching ratio is still nearly 1:1. So if cold nuclear fusion is to occur, and particularly if tritium is seen in abundance, it should be expected that neutrons would be emitted.

DETECTABILITY OF NEUTRONS. Neutrons are very convenient particles to detect, since they interact only with the nuclei of atoms and so can emerge from reaction vessels of substantial size unscathed and without having lost any energy. Similarly, large counters can be used without the problem of thin entrance windows, since neutrons enter into the mass of the counter without difficulty.

More specifically, neutrons can be detected either at their initial energy in the MeV range ("fast"), or after they have lost energy by successive collision with light material-- particularly hydrogen ("moderation.") The detection of fast neutrons can be achieved by photomultiplier tubes viewing the proton recoil in plastic or liquid scintillation material. Slow neutrons (those that have lost almost all their kinetic energy and are in thermal equilibrium at room temperature) are conventionally detected by the charged particles produced when the neutron is captured with high probability in the nucleus of an atom of B-10 (producing an alpha particle), or in a He-3 nucleus, producing a recoil proton. A noble gas, He-3 is used in the form of a proportional counter, while boron can be used either in the form of BF3 proportional counters or in the solid form, with the boron immersed in plastic or inorganic scintillator viewed by photomultiplier.

Additionally, neutrons can be detected after moderation by their capture in some material of very high capture cross section (like cadmium Cd), which produces several gamma rays that may, in turn, be detected by a photomultiplier viewing a scintillation detector. Similarly, neutrons moderated in water are almost entirely captured on the protons ("radiative capture"), giving rise to a deuteron plus a gamma ray of energy for the threshold of photodisintegration of the deuteron-- 2.2 MeV.

Finally, moderated neutrons may be captured in a trace element in the moderator (silver is a detector of choice) to produce a radioactive material that can be transported away from the experimental apparatus and counted separately with high efficiency at low background. The emitted radiation is typically a beta ray (negative electron), or a characteristic gamma ray following the beta decay.

Of course, the world has enormous experience since the 1930s in detecting neutrons and in detecting neutrons from the d+d fusion reaction.

SELECTION OF DATA. In what follows, we have tried to use published material, where available, or material formally prepared for publication and presented at formal meetings or as preprints distributed without restriction as to citation. It is important to include not only positive results (those that claim the detection of neutrons) but also negative results (those that have attempted to replicate the experimental procedure of others who find neutrons, but who fail to detect neutrons at a level of sensitivity substantially better than those who do find neutrons). Furthermore, in the case of the claimed detection of neutrons, the author of this subsection has in every case attempted to contact by telephone, letter, or FAX, the experimental group to determine their present knowledge of the production of neutrons.

Initial claims. The UU group in its initial publication
RLG cite claimed the detection of neutrons from d+d by virtue of the gamma ray emitted by the capture of the moderated neutron in the water bath surrounding the electrolytic cells. A very narrow peak of the pulse-height spectrum from the NaI scintillator was shown in the report,
RLG reproduce at the expected energy of 2.2 MeV. The text, however, claimed that the expected energy was 2.5 MeV(a)
RLG check and so narrow a window of the overall scintillation spectrum was shown that the reader could make no judgment as to the reality of the peak.

publications

These very questions were taken up by a group at MIT,
RLG cite Petrasso publication who showed that the photo peak at 2.2 MeV obtained at MIT from Cf spontaneous fission neutrons moderated in water and radiatively captured on protons is accompanied by other peaks from natural background that enable one to calibrate the energy. ~~and~~ Successive ~~interchange~~ between UU and MIT groups in ~~the scientific lit-~~ Nature

(a) corrected in a published erratum to 2.2 MeV. ...

cd

erature have demonstrated with high probability that the claimed detection of neutrons by the proton capture gamma ray at UU has been an artifact of the experimental apparatus.

The original publication from BYU presented the detection of neutrons as the sole experimental evidence for the existence of cold nuclear fusion. The neutrons were detected in a two-stage neutron counter-- first by the proton recoil in organic scintillator, followed within a few tens of microseconds by a signal from the capture of the moderated neutron on boron viewed by the same photomultipliers. This double detection of a single neutron serves substantially to reduce the ambient background due to gamma rays, although there remains background in the experiment due to gamma rays and due to real neutrons from cosmic rays and other sources. The group at BYU has chosen ~~to~~ attempt to vary the experimental conditions in order to obtain a greater rate of d+d fusion, and ~~so~~ has not presented much more data than the original paper on the detection of neutrons with that counter. In fact, BYU has been working in collaboration with other groups, notably at LANL, and also with a group at Yale University. The original claim of neutron detection five standard deviations above the background is somewhat reduced in statistical strength if one considers the degrees of freedom that are fixed by the presentation of a peak in one of a number of experiments and at a particular energy, and the like. Ordinarily, however, such a significant result can be brought up from the background by using different counting or detection equipment or by reducting background through improved shielding or by moving to underground site, or the like. It is the very ~~[illegible]~~ of the effect of cold fusion to be explored and demand that raises doubt still [illegible] reality of the phenomenon.

[illegible]

Typical of the ~~latter~~ is work presented by the group at Sandia National Laboratory,
RLG cite in which a site was found with substantially less background and results presented as follows for the neutrons produced in electrolytic fusion.
RLG cite

with more sensitive equipment is test

Many claims have been made for the production and detection of neutrons produced in electrochemical cells, but these claims almost uniformly have been withdrawn or moderated by the discovery of difficulties with the counter-- particularly with the BF3 counters used. In some cases, the counters are sensitive to humidity; in others to microphonic noise (vibration); or to other afflictions.

Dry fusion.

Results presented in April 1989 by a group at Frascati
RLG cite opened an entirely new opportunity for the observation of d+d cold nuclear fusion. In this work, deuterium gas at 60 atmospheres pressure (60 bar) was allowed to contact titanium lathe turnings in a stainless steel reaction vessel~~. That~~ that allowed the temperature of the sample to be varied either by heating or by cooling. No neutrons were observed from the hydriding reaction at room temperature or at elevated temperature, when viewed by a nearby BF3 counter. However, after cycling to nitrogen temperature, bursts of counts were obtained from the counter-- typically on the order of 20 counts per burst emerging over a period of

The author visited Frascati on 6/14/89

60 microseconds. One set of data was presented on counts obtained by cycling to nitrogen temperature, showing neutrons essentially only in these bursts. These experiments were soon dubbed "dry fusion"

A totally different type of neutron emission was claimed by the Frascati group following warming from nitrogen temperature over one weekend. A bell-shaped curve rising to a peak of 300 neutrons per ten-minute counting interval is reproduced below.
RLG do This, of course, is an important experimental result, and provoked great effort toward verification both at Frascati and at elsewhere. In a telephone conversation of 09/12/89
RLG cite the author was informed by Dr. M. Martone at Frascati that there has been no confirmation of either the burst results or of the continuous neutron emission from the d-Ti system or from any other dry fusion activity at Frascati. In addition, electrochemical cells operated without producing observable numbers of neutrons, and their operation was terminated during the month of July.

A group at LANL has conducted dry fusion work with Ti and Pd, and has presented results both at the Santa Fe meeting and in a preprint.

This group ~~at LANL~~ uses high-efficiency systems that moderate any fast neutrons emitted from experimental cells, detecting the moderated thermal neutrons in He-3 gas counters.
RLG check Bursts of neutron counts are sometimes observed 3000-5000?? seconds after the sample is removed from liquid nitrogen, at a time when the sample temperature is typically -30 C. Although such experiments were reported at the Santa Fe workshop in May, as of 09/18/89
RLG check with Menlove. no experiments have been done with 100% hydrogen gas replacing deuterium, and the natural check of splitting the counters among two counting channels has not been performed either.

fn

If a burst of 50 counts is observed in 18?? counters operated in parallel, then if those counters were randomly assigned (9 and 9) to two independent recording channels, that same burst of neutrons would be expected to produce on the order of 25 counts in each of the two channels. There is essentially zero statistical likelihood that one set of 9 counters would produce 25 or 50 counts, while the other set immersed in the same moderators would have no counts during the tens of microseconds during which the neutrons might be emerging into the counters.

Just this powerful and simple check has been used by a group at Sandia National Laboratory
RLG cite which has used counters split among three channels in order to guard against burst of counts that might otherwise be taken to be due to bursts of neutrons. In fact, in their measurements using deuterium gas on Ti or Pd, the Sandia group has on occasion seen bursts of counts in one counter set, unaccompanied by bursts of counts in the interspersed counters. They caution, "
RLG quote

Under favorable low-background conditions, Sandia has also looked for neutrons from electrochemical cells with the following results:
RLG quote

At the Santa Fe workshop, Moshe Gai of Yale presented results obtained in collaboration with Brookhaven National Laboratory, in which no neutrons were detected from electrolytic cells. Steven Jones of BYU agreed to provide to the Yale group his best efforts at a neutron-producing cold fusion apparatus, in a collaboration much to be encouraged between those who claim to be producing neutrons and those with a demonstrated capability of detecting neutrons from other sources. This collaboration has indeed proceeded, in a fruitful and satisfactory fashion, with a dry fusion source-- four cells of 60 grams of materials (each?), with several choices of Ti and other metals. Thus, the Steve Jones collaboration with Yale involves 7 investigators at Yale, and 130 hours of experimental data have been recorded on tape. Fast neutrons are detected in liquid scintillators, with 6 counters above the plane of the source and 6 below. Each count has a measured pulse shape and pulse height, and arrival time sufficiently accurate to do time of flight analysis, so that a single neutron has its kinetic energy overdetermined. The data can be played back in any of 3 modes:

Playback modes for Yale neutron spectrometer.

1. High efficiency-- 22% efficiency but "high background"

2. Intermediate-- 2% efficiency but intermediate background

3. Low background-- ?? efficiency but "very low background."

In playback in mode 1, two events are observed that might be interpreted as neutron bursts (with 5 counters and 6 counters respectively providing signals); but two similar "events" are observed without samples present. Data are very likely to be available by the time of our panel meeting in Chicago; at present all that can be said is that nothing sticks up above the background in "high background" mode, which is probably about ten times more sensitive than measurements at LANL.

Finally, a conference report from the Bhabha Atomic Research Center,

> "Cold Fusion Results in BARC Experiments, by P.K. Iyengar, Fifth International Conference on Emerging Nuclear Energy Systems (ICNES V), Karlsruhe, FRG (July 3-6, 1989)

provides text and tabulated results from several groups at BARC. These scientists report large amounts of tritium from electrolytic cells, discussed in the "tritium" section of this report. As for neutrons, Fig. 1 of the BARC report shows counts from neutron detectors observing a large electrolytic cell~~s~~, with the large peak at the right providing an estimated 2x10**7 neutrons in the 5 minutes following overpower trip of the electrolyzer. Fig. 2 of the BARC report shows dry fusion He-3 counter output during gradual rise of temperature of 20 g of Ti while deuterium gas was being pumped off.

It is also commented that samples could be loaded with deuterium gas at 1 bar and 900 C, and that "one such disc-shaped button loaded on Friday 16th June began emitting neutrons on its own, almost 50 hours after loading. It produced (about) 10**6 neutrons over a 85-minute active phase. The background neutron counter did not show any increase in counts over this time."

In a Telex of 09/13/89 from P.K. Iyengar, the author has learned that BARC "observes neutron production in bursts" and that counters with silver cathodes have detected neutrons by activation of the cathodes.

SECONDARY NEUTRON PRODUCTION. There are problems of consistency between the number of tritium atoms found in some of these experiments and the number of neutrons detected. For instance, in the BARC Table 1, line 1, 8x10**15 atoms of tritium are cited. If that was over a period of 4 hours, the production rate was some 5x10**11 per second. Ordinary d+d fusion would have produced a similar number of neutrons, but the text indicates only 2x10**7 neutrons, for a branching ration of 0.3x10**-8. The BARC abstract itself reads, "The total quantity of tritium generated corresponds to about 10**16 atoms suggesting a neutron to tritium branching ratio less than 10**-8 in cold fusion."

But even the assumption of some portion of [illegible] of the d+d → p+t signal will, t+d → n+He4 [illegible] while,

~~But~~ the tritium is presumably born at 1 MeV recoil energy, and at least half of the tritons are directed into a "thick target" of deuterated Ti or Pd. The yield of 14-MeV neutrons from the reaction t+d=n+He-4 is about 2x10**-5 per incident tritium, so that the neutrons observed are only 1/1000 as many as should have been generated by the nascent tritium alone.

??

Almost equally striking is the sentence in the BARC report, "Neutron and tritium production has been confirmed in all these cells as well," indicating that several groups at BARC have no difficulty in obtaining fusion products, whereas many groups in the U.S. have been unable to obtain any signs of fusion with extended efforts over many weeks.

*** In the opinion of the author (Garwin), the BARC report is the only significant evidence for neutron emission from electrolytic cells or from dry fusion. I will pursue the actual report. ***

Sincerely yours,

Dick Garwin

Richard L. Garwin

cc:

J. Bigeleisen, Stony Brook (Via BITNET to JBIGELEI AT SBCCMAIL)
D. Hoffman, Berkeley (Via BITNET to HOFFMAN AT LBL.GOV)
S.E. Koonin, CalTech (Via BITNET to KOONIN AT CALTECH)
J.P. Schiffer, Argonne (Via BITNET to SCHIFFER AT ANLPHY)
W.L. Woodard, DOE (Via FAX to 9 (202) 586-3119)

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Local options: Search RealNode

Date: 19 September 1989, 14:55:41 EDT
From: (R.L.Garwin (914) 945-2555) RLG2 at YKTVMV
IBM Fellow and Science Advisor to the Director of Research
P.O. Box 218
Yorktown Hts, NY 10598
To: (Jacob Bigeleisen (516) 632-7905) JBIGELEI at SBCCMAIL
HOFFMAN at LBL.GOV
KOONIN at CALTECH
SCHIFFER at ANLPHY
SMITH at ANLPHY
Subject: T-D thick target yields.
Reply-To: RLG2 at YKTVMV
Reply-Bit: RLG2 at WATSON
Reply-Xin: rlg2@ibm.com

For determining the 14-MeV neutron output from a 1-MeV recoil triton, we can refer to J.E. Bounden, et al, NUCLEAR INSTRUMENTS AND METOHDS, Vol. 33, 283-288 (1965). They built an tube accelerating 50:50 D-T against an Erbium target ErD1T1 and found thick-target yields stable in time at more than 10**8 neutrons per microcoulomb, for beam energies above about 200 keV.

If one does not require stability against T replacing D in the target (the reason Jim Coon devised the mixed D-T beam), one accelerates T against a D-loaded target and picks up a factor 4 in neutrons per microcoulomb.

Thus the yield is 4x10**8 / 6x10**12 or 7x10**-5 neutrons per triton. Recoil tritons will provide at least as many neutrons.

Dick Garwin

LEAR INSTRUMENTS AND METHODS 33 (1965) 283–288; © NORTH-HOLLAND PUBLISHING CO.

A NEUTRON TUBE WITH CONSTANT OUTPUT (10^{10} n/sec) FOR ACTIVATION ANALYSIS AND REACTOR APPLICATIONS

J. E. BOUNDEN, P. D. LOMER and J. D. L. H. WOOD

Services Electronics Research Laboratory, Baldock, Herts, England

Received 22 September 1964

npact source of fast neutrons capable of producing well
10^{10} n/sec has been developed. The tube, which uses the
reaction consists of an r.f. ion source from which a mixture
uterons and tritons are accelerated onto a loaded erbium target. A life of at least 100 hour has been achieved. The design features which lead to this high output and long life are discussed.

The application of the tube to reactor instrumentation and activation analysis is briefly described.

troduction

e present paper describes a sealed-off fast neutron
ce which gives a continuous yield of 10^{10} neutrons/
or over 100 hour. The source, which uses the D-T
tion ($D + T \rightarrow n + He^4 + 17.6$ MeV) is simple
compact compared with an accelerator and has the
r advantage of a constant output over a long
od. The stable neutron output and reliability in use
particular advantages in the application of the
ce to industrial problems requiring routine activa-
analysis, such as the determination of oxygen in
, and to the production of short-lived isotopes.
neutron output may also be modulated over a
e range of pulse lengths and repetition frequencies,
required for more sophisticated reactor experi-
ts[1]). For these purposes it may be assembled into a
iameter container for insertion in the reactor.

he main advance offered by the present source over
vious sealed-off sources[2–4]) is an increase in neu-
output by a factor of from 20 to 100 to bring it
hin the levels of interest for activation analysis.

esign factors

he design criteria for a neutron source using the
T reaction are determined largely by the efficiency
the reaction as a function of the ion accelerating
tage and by the associated target problems of life
d power dissipation. These criteria are the same for a
tinuously-pumped accelerator or a sealed-off
tron tube except in consideration of target life. In
ler to achieve neutron outputs of 10^{10} n/sec, ion
rents of at least 200–300 μA are needed. This re-
sents a flow of gas at a rate of several cc at NTP
hour. Thus in a time of the order of an hour, a 1
tritium-loaded target will be diluted with deuterium
m the ion source, sufficiently to halve the neutron
put. This has been confirmed by all users of ac-
lerators, the best results being those obtained by Coon[5]) with very thick titanium targets having a half-life of 600 μA hour/cm^2.

A large improvement can be obtained by using a mixture of deuterium and tritium in both target and ion source. Then the percentages of tritium and deuterium in the target should remain unchanged by ion bombardment over very long periods. Experiments confirming this were carried out by Coon[5]) using the D(d,n) reaction; the neutron output remained constant throughout experiments in which a total of 3 C/cm^2 bombarded the target. The use of a mixture of deuterium and tritium is precluded in a continuously pumped accelerator because of the attendant health hazard and the large amount of tritium used. In a

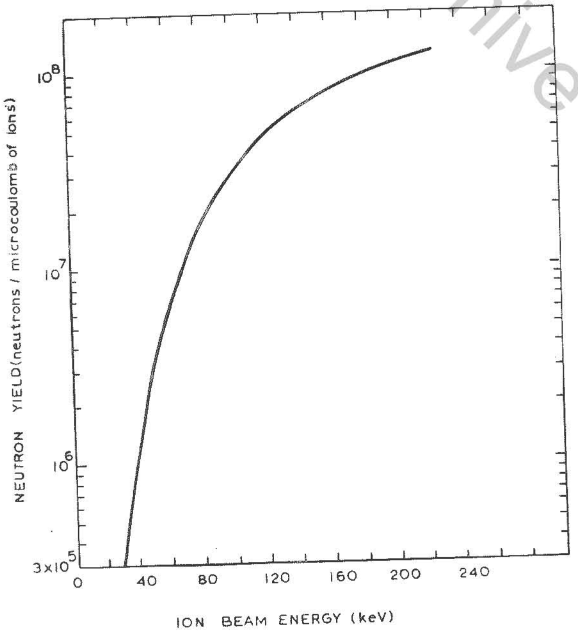

Fig. 1. Calculated neutron yield from a thick erbium target as a function of the ion beam energy. Ion beam composition 50% D_I^+ 50% T_I^+. Target composition Er $D_I T_I$.

VOLUME 63, NUMBER 12 PHYSICAL REVIEW LETTERS 18 SEPTEMBER 1989

Cluster-Impact Fusion

R. J. Beuhler, G. Friedlander, and L. Friedman
Chemistry Department, Brookhaven National Laboratory, Upton, New York 11973

(Received 9 June 1989)

Deuteron-deuteron fusion, detected via the 3-MeV protons produced, is shown to occur when singly charged clusters of 25 to 1300 D_2O molecules, accelerated to 200 to 325 keV, impinge on TiD targets. The energy and cluster-size dependence of the fusion rate are discussed. The fusion events are shown to originate from the cluster-ion impacts rather than from D^+ or D_2O^+ ions in the beam. The observed rates may be correlated with the compressions and high energy densities created in collision spikes by cluster-ion impacts.

PACS numbers: 79.20.Rf, 25.45.−z, 47.40.Nm, 52.50.Lp

The impact of accelerated cluster ions on solid surfaces has been shown to produce very high transient particle and energy densities.[1] The experiments reported in this Letter show that singly charged, heavy-water cluster ions containing between 25 and 1300 D_2O molecules and accelerated to energies up to 325 keV can, on impact with titanium deuteride targets, generate thermonuclear D-D fusion reactions.

The apparatus used for the experiments is shown schematically in Fig. 1. The ion source and the techniques for mass analysis and for acceleration of water cluster ions have previously been described in detail.[2] Water molecule ions in helium carrier gas were generated in a corona discharge. The weakly ionized gas mixture was expanded through a nozzle and skimmer into a high-vacuum system. As discussed previously,[2,3] a combination of mass analysis and careful determination of secondary-electron yields produced by impact of cluster ions on a target suffices to determine the m/e ratios of the ions and to count the number and kind of atoms in the cluster.

The cluster ions prepared by these techniques were subjected to quadrupole mass analysis[2] and electrostatic focusing before introduction into a Cockroft-Walton accelerator approximately 1 m long. After acceleration, ions passed through an aperture into a vacuum chamber containing a TiD target of about 1-cm^2 surface area at ~45° to the beam axis and approximately 1.5 cm from a 300-mm^2 Ortec "ruggedized" silicon solid-state detector. The active surface of the detector was covered with a 50-$\mu g/cm^2$ layer of aluminum.

The cluster beam current was monitored by measurement of secondary electrons ejected from the TiD target (i.e., measurement of apparent positive-ion current to the target). Cluster-ion intensity measurements are subject to error when a small fraction of the ions make grazing collisions with the edges of the column exit aperture. Such collisions produce low-mass fragments [e.g., 300-eV deuterons from 300-keV $(D_2O)_{100}$ clusters] that can eject secondary electrons from the target but do not have enough energy to produce D-D reactions. Careful attention to optimization of secondary-electron distributions is required to ensure proper beam focusing, particularly when the beam energy is varied. Relative values of pri-

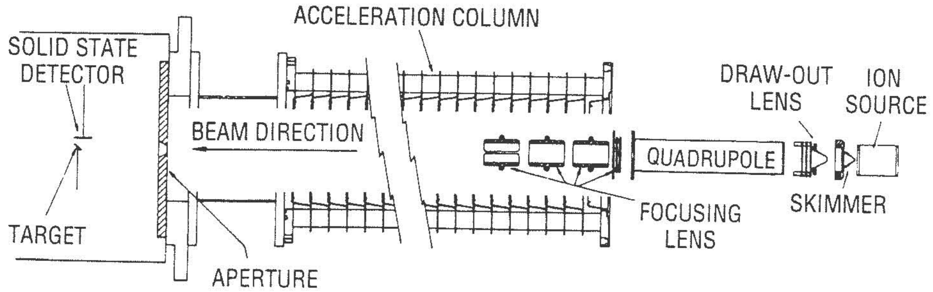

FIG. 1. Schematic diagram of the apparatus. A mixture of D_2O and He gas is ionized in a corona discharge in the ion source and expanded through a supersonic nozzle into a differentially pumped region between nozzle and skimmer. Cluster ions pass through the skimmer, are extracted with 10–50 eV by the draw-out lens, and mass analyzed in the quadrupole mass spectrometer using a low-frequency (~292 kHz) power supply. The mass-analyzed ions are focused and then accelerated in a Cockroft-Walton column. Ions traverse an ~1-cm aperture and impact on a TiD target attached to a Keithly picoammeter. A silicon solid-state detector ~1 cm from the target is used to measure protons, tritons, and x rays produced by cluster impact on the TiD target.

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&EXIT

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Date: Fri, 15 Sep 89 14:15 EDT
From: JBIGELEISEN@SBCCMAIL.BITNET
Subject: Tritium in Cold Fusion
To: RLG2@YKTVMV.BITNET
X-VMS-To: in%"RLG2@YKTVMV.BITNET"

State University of New York at Stony Brook
Stony Brook, NY 11794-3400

Jacob Bigeleisen
Professor
Chemistry
516-632-7905
15-Sep-1989 02:06pm EDT

FROM:	JBIGELEISEN	
TO:	Remote Addressee	(_SCHIFFER@ANLPHY.BITNET)
CC:	Remote Addressee	(_RLG2@YKTVMV.BITNET)

SUBJECT: Tritium in Cold Fusion

John:

Thanks for your BITNET message of 13 September 1989 with your calculation of the secondary neutron yield. Today I received section M of the external reports from Bill Woodard. It is AZPH-TH/89 by Harley and Rafelski dated 29 August 1989. It comes to the same conclusion: Kevin Wolf is in trouble. His neutron and tritium measurements are self inconsistent. I also received a report from Martin, who is doing independent work at Texas A&M. He has now run many cells, some with and some without gas recombination. He uses the same Pd and Ni anodes as Bockris and finds no tritium. I now have detailed reports from the Oak Ridge groups.

My trip to Japan has been postponed. I will be updated my tritium report to include all the above as well as other additional information, including the ANL work, which arrived after I prepared the 7 September draft. I will be sending you this material early in the week of 18 September. JAKE.

EASYLINK MBX 1844443A001 13SEP89 03:44/06:58 EST

13 SEP 89 8.73

-R.L. GARWIN-

VIA: 137456

TO: 62947588

RCA SEP 13 0434
IBMRESRCH YKHG UD

IBMRESRCH YKHG UD
1171017 BARC IN SEPT 13, 1989 1405HRS(IST) BARC/INTLX/1679

FOR: DR.RICHARD L GARWIN IBM RESEARCH DIVISION THOMAS J WATSON
RESEARCH CENTER NY 10598

FROM: DR P K IYENGAR DIRECTOR B A R C BOMBAY INDIA
(FAX NO. 2048476)

DEAR DR.GARWIN:

THANK YOU FOR YOUR TELEX OF SEPTEMBER 7, 1989. SINCE THE PRESENTATION OF MY PAPER AT THE KARLSRUHE MEETING WE HAVE CONTINUED TO EXPERIMENT WITH PALLADIUM AND TITANIUM, BOTH BY ELECTROLYSIS AND GAS ABSORPTION. WE CONSISTENTLY SEE TRITIUM AS WELL AS NEUTRON PRODUCTION IN BURSTS. THE SAME CELLS WITH HIGHER CURRENT HAVE PRODUCED NEUTRON BURSTS AS WELL AS TRITIUM BURSTS. BURSTING NATURE OF TRITIUM PRODUCTION ALONG WITH NEUTRONS HAS BEEN OBSERVED BY US RECENTLY WITH CELL 1 IN TABLE 1 BY USING AN ON-LINE TRITIUM MONITOR ALONG WITH A NEUTRON DETECTOR. THIS TIME WE USED GM COUNTERS WITH SILVER CATHODES TO DETECT NEUTRONS BY ACTIVATION. NEW CELLS HAVE ALSO BEEN SUCCESSFUL. THE AUTORADIOGRAPHIC TECHNIQUE HAS BEEN TRIED OUT WITH GAS LOADED PALLADIUM FOILS AND HAS SHOWN SIMILAR RESULTS AS DESCRIBED IN MY PAPER EXCEPT THAT WE DO NOT SEE SPOTS IN THE CASE OF PALLADIUM.

AS REGARDS YOUR QUERY REGARDING BRANCHING RATIO, IT IS TRUE THAT ENERGETIC TRITONS SHOULD PRODUCE 14 MEV NEUTRONS IN THE PALLADIUM MATRIX. THE BRANCHING RATION OF 10&&-8 QUOTED IN OUR PAPER WAS DEDUCED USING ONLY THE NEUTRONS OBSERVED DURING BURSTS. HOWEVER, IF ADDITIONAL AMOUNT OF NEUTRONS POSSIBLY PRODUCED BETWEEN BURSTS BUT SUBMERGED IN THE BACKGROUND IS TAKEN INTO CONSIDERATION ALONG WITH THE TOWER EFFICIENCY FOR DETECTION OF 14 MEV NEUTRONS, THE NEUTRONS TO TRITIUM BRANCHING RATION WOULD BECOME SOMEWHAT HIGHER,PERHAPS 10&&-6 OR 10&&-5. ALTHOUGH THE INCONSISTENCY MENTIONED BY YOU WOULD DISAPPER IT WOULD IMPLY THAT BULK OF THE NEUTRON PRODUCED WOULD BE OF 14 MEV ENERGY. WE ARE, THEREFORE, TRYING TO MEASURE THE SPECTRUM OF NEUTRON EMISSION CAREFULLY. HOWEVER, IT MAY ALSO TURN OUT THAT THE INTEGRATED PROBABILITY OF A(TD) REACTION CAUSED BY TRITONS RELEASED WITHIN THE LATTICE MAY BE DIFFERENT COMPARED TO MEASURED BEAM TARGET VALUES. IN ANY CASE THE ABOVE ARGUMENTS WILL LEAD TO THE CONCLUSION THAT THE TRUE BRANCHING RATIO IN THE (DD) FUSION IS SMALLER THAN 10&&-8 FOR NEUTRON PRODUCTION CONFIRMING THAT COLD FUSION IS ESSENTIALLY ANEUTRONIC IN NATURE.

AS REGARDS THE CONSOLIDATED BARC REPORT, IT IS STILL UNDER PREPARATION EVENTHOUGH SEVERAL PARTS OF IT ARE READY. I SHALL MAIL IT TO YOU THE MOMENT THIS IS COMPLETE, HOPEFULLY WITHIN A FEW WEEKS.

LET ME ALSO ENDORSE YOUR OBSERVATION ''SCIENCE MARCHES ON'', IN SPITE OF GOOD AND BAD REPORTS.

WITH BEST WISHES,

SINCERELY YOURS

P.K.IYENGAR

OVER PL ACK

IBMRESRCH YKHG UD

10/13/89

19 SEP 89 13. 61

-R.L. GARWIN-

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

September 11, 1989

To: Cold Fusion Panel

Subject: October 13 Meeting

The Hilton Hotel at Chicago's O'Hare airport does not have a conference room large enough to accommodate our group, so the meeting will be at the:

Hampton Inn O'Hare
3939 North Mannheim Road
Schiller Park, IL 60176
Telephone 1-800-444-8448

A block of rooms has been reserved under "ERAB Cold Fusion" but I suggest you call to confirm your reservations, especially if you will be arriving late.

The Inn is about two minutes from the airport, and they have courtesy van service from the airport outside the lower level baggage claim area.

The rate is $49 plus tax including a continental breakfast which will be available outside our meeting room. There will also be a working lunch. There is no other meal service at the Inn but for those arriving the evening before I am told there are several places to eat within walking distance.

The meeting will begin promptly at 8:00 a.m. and should adjourn at 5:00 p.m. or shortly thereafter. The conference room assigned us will be posted on the Inn's Calendar of Events.

Bill

William L. Woodard
Secretary
Cold Fusion Panel

-R.L. GARWIN-
12 SEP 89 13.03

SUSB -IL-14

Tritium

Report Prepared for the ERAB Panel on Cold Fusion

Jacob Bigeleisen
Department of Chemistry
State University of New York, Stony Brook
Stony Brook, New York 11794 - 3400

7 September 1989

Tritium

One branch of the D - D reaction produces 1 MEV tritons and 3 MEV protons. In conventional fusion reactions the branch to produce tritium is equal to the neutron production branch. All experiments to date , in the range above 1 KEV, show that this ratio is insensitive to the deuteron energy. Theory predicts that the ratio will not change significantly down to deuteron energies in the volt to millivolt range. In a few experiments there have been direct searches for emitted high energy tritons[1] or protons.[2] These experiments give fusion rates 10^{-1} and 10^{-2}, respectively, lower than the neutron production rate reported by Jones[3], 1×10^{-23} fusions/sec./D - D pair. A number of searches have been made for the tritium accumulated during the electrolysis of D_2O with palladium cathodes. In such experiments it is important to determine the initial tritium content of the D_2O and take cognizance of the fact that the electrolysis of the D_2O will enrich the natural occurring tritium in the heavy water.

The detection of tritium by measurement of its beta decay is inherently a less sensitive probe of the D - D reaction than the direct measurement of neutron production or charged particle production. 10^7 tritium atoms give 1 β^- particle per minute.

Tritium is produced in the atmosphere by cosmic ray bombardment. Most of the cosmic ray produced tritium ends up in the oceans and in rivers. The "natural" abundance of tritium varies widely and was greatly increased by atmospheric testing of thermonuclear weapons in the '50s and in the early '60s. The order of magnitude of tritium in ordinary water is $T/H = 10^{-18}$ (1 TU). Sources vary from 1 to 200 TU. The production of heavy water from ordinary water is even more efficient in the enrichment of tritium than deuterium from the feed material. Most of the heavy water currently available is produced by the H_2S - H_2O dual temperature exchange process (GS process). The tritium content of fresh heavy water produced by the GS process is 68 dpm/ml. D_2O/TU feed. Processes which are more efficient than the GS process in heavy isotope enrichment will have a minimum tritium specific activity of 50 dpm/ml. D_2O/TU feed. Heavy water currently being sold on the open market has a specific activity in the range 120 - 180 dpm/ml. D_2O. There are sources with a specific activity as high as 10^4 dpm/ml. D_2O.

Most of the work done to date on the search for tritium produced in the electrolysis of D_2O in cells with palladium cathodes has been done in open cells. The measurements are frequently limited to assays of the specific activities of the starting D_2O and the electrolyte after electrolysis. In general, there have been periodic additions of D_2O to replace the D_2O decomposed to form palladium hydride and $D_2(g)$. To determine how much tritium, if any, has been produced requires a complete inventory of the tritium at the beginning and end of the experiment. From the data on the current and duration of the electrolysis it is possible to estimate the amount of D_2O which has been electrolyzed. Electrolysis will enrich the tritium in the D_2O of an electrolytic cell. The amount of enrichment is primarily a function of the amount of water electrolyzed for a given type of cathode. It can reach a factor of 5 when 95% of the initial charge of water is electrolyzed. Thus a careful analysis of an electrolytic experiment must be carried out if one is to interpret tritium specific activities after electrolysis below 1000 dpm/ml. D_2O as anything other than electrolytic enrichment.[4]

Most of the work reported to date on the search for excess tritium produced in electrolytic cells can be accounted for by the electrolytic enrichment process. This includes the original report by Fleischmann and Pons[5], and experiments at BNL[6], ORNL[7], Sandia[8] and Cal Tech.[9]

A small number of experimenters report occasional irreproducible amounts of excess tritium in their D_2O samples taken from their electrolytic cells after days of operation. This includes observations by Storms[9] at Los Alamos and Scott[7a] and Fuller[8b] at ORNL. In these experiments the specific activity of the tritium in the D_2O shows an increase of about a factor of 5 - 100 above the initial specific activity. Each of these investigators have numerous experiments carried out in identical cells which show no increase in the tritium specific activity above the electrolytic enrichment level.

McBreen[11] at BNL has carried out one experiment in a closed cell, with total recombination of the D_2 and O_2. 120 ml. of 1 M D_2O was electrolyzed at a current of 1 ampere for four months. The tritium specific activity increased from 153 dpm/ml D_2O to 202 dpm/ml. D_2O. The deuterium inventory in the Pd cathode and in the gas phase is negligible. Thus the enrichment does not come from the isotope effect in electrolysis. This experiment gives a net increase of 6×10^4 T atoms/sec. or 6×10^9 T atoms/Faraday.

Two groups[12, 13] find tritium at levels of 10^{12} to 10^{14} T atoms/ml. D_2O after periods of electrolysis of the order of hours. This amount of tritium cannot be produced by electrochemical enrichment with the D_2O volume reductions reported. The results of the Bockris[12] group at Texas A & M for cells in which excess tritium was found are given in Table 1 of their paper, reproduced here. Excess tritium is not found in all of their cells. A lisitng of cells in which no excess tritium was found is given in their Table 4. The Bockris cells are 0.1 M in LiOD and have nickel anodes. They precipitate nickel oxide during the electrolysis; some nickel is also electroplated out on the palladium cathode. In one experiment, A8, the specific activity of the D_2 gas produced by the electrolysis was measured. It is 100 times that of the electrolyte. $D_2(g)$ containing tracer amounts of tritium and in equilibrium with $D_2O(l)$ has a specific activity of 0.6 that of the liquid D_2O. If the tritium is formed during electrolysis, then this result suggests that it is formed in the chemical species DT and that all the tritium in the liquid D_2O is the result of slow isotopic exchange of the DT(g) with $D_2O(l)$[14]. Wolf[15] et. al. at Texas A & M have looked for neutron production in Bockris type cells. An upper limit to their neutron production rate is 1 neutron/second, which is 10^{-10} times that of the tritium production rates reported by Packham et. al.[12] This large discrepancy from the usual equal production rates for neutrons and tritons leads one to question whether the excess tritium found in the electrochemical cells results from the D - D nuclear reaction. Another source of concern is the fact that 1 MEV tritons will react with deuterium to produce 14 MEV neutrons. With the claimed triton production rate, 10^{10} tritons/sec., one should find (number to be inserted by RLG) neutrons/sec from the D - T reaction in these cells.[16]

The BARC[13] group have found amounts of tritium comparable to the Bockris group in the D_2O electrolyte from cells in which electrolysis was carried out for a few days with currents varying between 1 to 100 amperes. The BARC group also looked for neutrons using BF_3 counters embedded in paraffin. They report neutron bursts of up to 100 neutrons in a 100 μ second time interval. Their integrated neutron yield is 10^{-8} times that of their integrated tritium yield.

The BARC group have also looked for neutrons in the thermal cycling of Ti pressurized with D_2 gas. They report neutron emissions for periods of 30 minutes to 7 hours after cycling between room temperature and 77 °K. Autoradiograhs of the Ti targets from these experiments show intense spots which the authors attribute to beta emission from the decay of the tritium embedded in the Ti lattice.

Conclusions

The experiments carried out to date, which include the large number of null experiments, the few experiments which are irreproducible and in which excess tritium is found, and the large ratio of tritium to neutron production in these experiments, do not provide convincing evidence for the production of tritium by cold fusion phenomena. Clearly additional experiments are desirable to clarify the origin of the excess tritium which is occasionally observed.

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10. Letter from R.J. Jensen, ADR: 89-364, to Jacob Bigeleisen 18 August 1989.

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14. J. Bigeleisen, letter of 26 Auguat 1989 to J.O'M. Bockris.
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TABLE 1
CELL IDENTIFICATION, ELECTRODE TREATMENT, SOLUTION TYPE AND TRITIUM ACTIVITY OF ELECTROLYTE SAMPLES PERFORMED ON 1219 LSC

CELL	ELECTRODE PRETREATMENT[a]	SOLUTION	CORRECTED ^{3}H ACTIVITY (dpmml^{-1})
A1	No treatment	0.1M LiOD	3.8×10^4
A2	No treatment	0.1M LiOD + 0.1mM NaCN	
	After 16 days at 50 mAcm^{-2} then for 8 hours at 500 mAcm^{-2} (5/1/89)		168
	50 mAcm^{-2} for 4 days (5/5/89)		134
	50 mAcm^{-2} for 3 hours, 110 mAcm^{-2} for 2 hours, 200 mAcm^{-2} for 20 minutes (5/6/89)		1.1×10^4
	50 mAcm^{-2} (5/7/89)		1.4×10^4
	(5/7/89 - 5/13/89)		1.1×10^4
	(5/13/89 - 6/6/89)		7.5×10^3
A3	Anneal	0.1M LiOD	4.9×10^6
A4	Anneal	0.1M LiOD + 0.1mM NaCN	1.2×10^5
A5	Acid Etch	0.1M LiOD	3.7×10^6
A6	Acid Etch	0.1M LiOD + 0.1mM NaCN	3.3×10^4
A7	Electrochemical	0.1M LiOD	
	Before high current density		102
	After 2 hours at 500 mAcm^{-2}		5223
	After 6 hours at 500 mAcm^{-2}		5.0×10^5
	After 12 hours at 500 mAcm^{-2}		7.6×10^5
A8	Electrochemical	0.1M LiOD + 0.1mM NaCN	
	After 16 days charging and 8 hours high current density (5/1/89)		192
	Electrolyte levels after 6 weeks at 50 mAcm^{-2}		5.0×10^5
	Recombined gas levels after 2 weeks of external recombination at 50 mAcm^{-2}		5.0×10^7
B3 (3mm)	Anneal	0.1M LiOD	6.3×10^4
B5 (3mm)	Acid Etch	0.1M LiOD	48
CELL 1 (6mm)	No treatment	0.1M LiOD	117

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[a] Key for electrode surface pre-treatment: Anneal = annealing at 800 °C, 10^{-6} torr, 8 hours; Acid etch in 5M HCl, 15 minutes; Electrochemical oxide removal, 2 hours

TABLE 4

DETAILS OF CELLS THAT PRODUCED NO TRITIUM
WITH 1410 LSC (CORRECTED ACTIVITY)

EXPERIMENT	$dpmml^{-1}$
3mm x 3cm Ti Cathode in 0.1M LiOD with internal gas recombination	275
3mm x 3cm Pd Cathode in 0.1M LiOD with internal gas recombination	235
3mm x 3cm Ti Cathode in 0.1M LiOD with internal gas recombination	285
0.5mm x 1cm Pd Cathode in 0.1M LiOD with internal gas recombination	55
4mm x 2mm Pd disc Cathode in 0.1M LiOD with internal gas recombination	365
0.5mm x 1cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured)	315
1mm x 4cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured 7/18/89)	75
1mm x 4cm Pd Cathode in 0.1M LiOD with external gas recombination (recombined gases measured 7/21/89)	33
1mm x 4cm Pd Cathode in 0.1M LiOH (H_2O) No gas recombination	0
1mm x 4cm Pd Cathode in 0.1M LiOH (H_2O) No gas recombination	18

UNIVERSITY OF
ROCHESTER

COLLEGE OF ARTS AND SCIENCE
DEPARTMENT OF CHEMISTRY

John R. Huizenga
Tracy H. Harris Professor

September 5, 1989

Professor T. Kenneth Fowler
Department of Nuclear Engineering
University of California, Berkeley
Berkeley, California 94720
Fax 415-643-9685

Dear Ken:

In addition to the items in the Introduction of our Interim Report (paragraph 2 may require some updating), we may want to include some of the following items in the introduction of our final report.

1. A statement that from the outset two very different claims were made, namely large amounts of excess heat (Fleischmann and Pons) in the watt range (which, if nuclear fusion, requires the liberation of some 10^{12} particles per second) and a very low-level neutron intensity by Jones et al (which, if nuclear fusion, produces only 10^{-13} watt and is of no interest as a power source). Furthermore, the initial release of Fleischmann and Pons contained a major discrepancy of over a billion between the claimed intensities of the excess heat and nuclear particles and required an, as yet, unknown nuclear process for consistency. The Jones et al claim did not adequately differentiate whether their reported neutrons were coming from bursts or by random emission (some statement like this will allow us to treat the bursts under the Jones et al claims). In a sense some of the above is now in the second paragraph of our Interim Report, however, it should be restated to emphasize how different the two initial claims really were.

2. Some history of earlier work such as that of Paneth and Peters loading of Pd with hydrogen gas, the electrolysis of H_2O by Tandberg to get H into a Pd electrode (and after deuterium was discovered in 1932, his electrolysis of D_2O), and something about muon catalyzed fusion and the reason it hasn't produced useful energy.

3. A table of low-energy reactions of hydrogen isotopes including Q values, branching ratios, reactions per second per watt of energy output, etc. Somewhere in the Introduction it should be emphasized that if a reported excess heat is to be ascribed to nuclear fusion then it is absolutely essential to establish the presence of fusion products (preferably more than one such product) at the required corresponding intensities. Furthermore, from an experimental point of view the positive detection of particles is orders of magnitude more sensitive than the detection of excess heat.

467 Hutchison Hall
University of Rochester
Rochester, New York 14627
(716) 275-4217

4. A paragraph of two (and maybe a table or graph) on calculated fusion rates in isotopic hydrogen molecules including an elementary discussion of barriers, tunneling, etc. and possibly a statement about the hypothetical enhancements of the electron mass required to bring cold fusion rates into the range of reported observations. Possibly reference to the work in the USSR (e.g. by Deryagin and collaborators) on the possibility of nuclear reactions during fracture of solids (and the possible relation of this work to the claimed neutron bursts).

5. Something about Pd having a face-centered cubic lattice with 4 atoms per cell and a cell distance $a=3.88A^o$ while the atoms of ^2H occupy the octahedral sites with four such sites per cell with a nearest ^2H-^2H distance of $2.74A^o$. Other ^2H atoms later occupy tetrahedral sites, 8 such possible atom sites per cell, with closest ^2H-^2H distance of approximately $1.7A^o$. The bond distance in $(^2H)_2$ gas is much smaller at $0.74A^o$, leading some investigators to search for fusion in a gaseous deuterium. Then present some information on loading of ^2H in Pd from an experimental point of view where saturation occurs at a ^2H/Pd ratio of 0.8. Further loading can be accomplished by ion implantation where ^2H/Pd ratios of over 1.3 have been reached.

Although it may be worthwhile to mention some or all of these topics in a general way in the Introduction, any detailed discussion should go into appendices.

Sincerely,

John

John R. Huizenga

CC: J. Gavin, Jr. Fax 516-575-3631
S.E. Koonin Fax 818-564-8708
W. Woodard Fax 202-586-3119

RLG copy.

Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
(914) 945-2555

September 5, 1989
(Via Airborne Express)

Dr. William L. Woodard
Cold Fusion Panel Secretary
Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Dear Bill,

I write primarily to enclose COLD FUSION NEWS No. 19 by D.R.O. Morrison. Would you please see that this is distributed to the Panel.

For your information, I have received no response to my letter of 08/16/89 to Professors Fleishmann and Pons; you distributed this to the Cold Fusion Panel with your note of 08/21/89.

Incidentally, as far as the appendix to our Panel report is concerned, it should list my visit of 06/09/89 to Frascati (Rome), Italy.

I have read the paper by P.K. Iyengar, Cold Fusion Results in BARC Experiments, which you distributed 08/28/89. I want to comment only on the stated branching ratio of "less than 10**-8" between the neutron branch and the proton branch of the d + d reaction. On this remark, I need quantitative support from Koonin or Schiffer. The problem, of course, is that d + d produces tritium of 1 MeV, accompanied by a proton of 3 MeV. If you refer to page 9 of COLD FUSION NEWS No. 19, you see Morrison arguing that the 3 MeV protons would give large numbers of neutrons from the charge exchange reaction p + n = n + p, but as indicated in my enclosed letter to Etienne Roth the protons actually have insufficient energy to produce neutrons from deuterons in this way. The problem is that the p + n is bound in a deuteron with 2.2 MeV energy, but p + p product state (after charge exchange) is not bound.

Also Adjunct Professor of Physics at Columbia University
(Views not necessarily those of IBM or Columbia)

On the other hand, the 1 MeV tritons as they slow down certainly will cause a very substantial yield of 14 MeV neutrons from the d in the cathode. Note that this would be the case whether the tritium is produced on the surface or in the interior of the cathode, since the tritium nuclei directed into the bulk would cause this reaction. It seems to me that the yield would be more like 10**-5 than 10**-8, which indicates to me that wherever the BARC tritium comes from, it is not d + d reaction. Note that this is true even if (especially if) the fusion took place in moments of hot fusion, during the disruption of the material as hydrogen was introduced.

I will try to contact P.K. Iyengar at the Bhabha Atomic Research Centre for more information, but I don't guarantee results.

Finally, I enclose a paper I received from Dr. Michael Danos. Perhaps you already have it. Here is also a copy of a question I sent him, and his reply just received.

Sincerely yours,

Richard L. Garwin

Encl:
- 08/25/89 COLD FUSION NEWS No. 19 by D.R.O. Morrison. (082589DROM)
- 07/18/89 LTR RLG to E. Roth re branching ratio in fusion. (071889..ER)
- 07/24/89 LTR M. Danos to RLG re "Coulomb Assisted Cold Fusion in Solids." (072489..MD)
- 08/11/89 LTR RLG to M. Danos. (081189..MD)
- 08/21/89 LTR M. Danos to RLG. (082189..MD)

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